Project Jack Rabbit: Field Tests

CSAC 11-006

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Homeland Security

Science and Technology

Chemical Security Analysis Center

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For

U.S. Department of Homeland Security

Science & Technology Directorate

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DISCLAIMER

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Project Jack Rabbit: Field Tests

EXECUTIVE SUMMARY

The Jack Rabbit Project, sponsored by the United States (U.S) Department of Homeland Security (DHS) Transportation Security Administration (TSA), was a study designed to improve the understanding of rapid, large-scale releases of pressurized, liquefied toxic inhalation hazard (TIH) gases. The project involved outdoor release trials of 1- and 2-ton quantities of chorine and anhydrous ammonia in 10 successful trials occurring in April and May of 2010. The project was managed by the Chemical Security Analysis Center (CSAC), part of the DHS Science and Technology (S&T) directorate, and executed at Dugway Proving Ground (DPG), a U.S. Army testing installation in Utah.

The objectives of the Jack Rabbit Project follow:

1. Execute a reduced-scale test of each of two chemicals (chlorine and anhydrous ammonia) to identify potential vulnerabilities before full test conduct.
2. Develop and evaluate a mechanism for the controlled, rapid release of liquefied, pressurized gases from containment to approximate the conditions hypothesized to generate a persistent vapor-aerosol cloud in a 90-ton railcar release.
3. Characterize the vapor/aerosol cloud movement, behavior, and physiochemical characteristics and compare those characteristics with known observations and testing of large-scale releases of the testing materials.
4. Determine if anhydrous ammonia can potentially act as less expensive and less dangerous dense gas for studying the component phenomena of large scale releases of dense gas TIH materials.
5. Field and evaluate instrumentation that can be used for the study of the large-scale release of the testing materials, and develop and evaluate testing methodology for future additional and potentially larger-scale tests.

Detection instrumentation was deployed out to a range of 500 meters, with some point detection MiniRAE instruments recording data at multiple heights, including 1-m, 3-m, and 6-m. Additionally, data was recorded from several stand-off instruments and video stations to capture the behavior of the cloud as it dispersed downwind. During the tests, meteorological, FTIR and UV optical, paper detection, thermal couple, and bubble sampling data were collected. The release trials were also recorded on digital video. Comprehensive studies and analyses of the data will be conducted through additional follow-on tasks in FY 2011 when all datasets have been collected, qualified, and made available.

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1.0 INTRODUCTION

1.1 Background

The United States (U.S.) Department of Homeland Security (DHS) and the Transportation Security Administration (TSA) tasked Edgewood Chemical and Biological Center (ECBC), with the support of the Chemical Security Analysis Center (CSAC), part of the DHS Science and Technology (S&T) Directorate, to study and improve the understanding of rapid large-scale releases of pressurized, liquefied toxic inhalation hazard (TIH) gases. DHS is concerned by the risk that an accidental or intentional release of a TIH material poses to our population. Millions of tons of TIH materials, such as chlorine and anhydrous ammonia, are transported annually in the U.S. by rail, road, water, and pipeline as pressurized, liquefied gases, frequently through highly populated areas. DHS has a critical need to improve the understanding and modeling of large-scale releases, and to provide better guidance to emergency responders and planners and mitigate the potential threat.

Currently, the expected behavior of large-scale releases of many toxic industrial chemicals (TICs) is extrapolated from experiments involving other gases, using different (non-validated) scaling, or with objectives that differ from the current needs of TSA. Therefore, TSA is funding experimental TIC field release studies to improve understanding of the behavior and associated phenomena. Several areas of the large-scale release phenomenology have been identified as requiring study and improved understanding:

1. *Scaling*. The amount of energy required to completely vaporize 60 to 90 tons of a liquefied, pressurized gas overwhelms the energy, which is available via superheat and the environment near the release site. This consideration, and others, needs to be investigated to understand how the behavior of well-understood, smaller puff releases scale to a railcar release.
2. *The Vapor/Aerosol (Mist) Cloud*. When a liquefied, pressurized gas is released from containment at small scales, there is enough air and energy entrained into the escaping jet to vaporize all the liquid. However, at the scale of a rapid railcar release, the available energy is not sufficient to vaporize the liquid, resulting in a vapor/aerosol cloud that is colder, denser, and more persistent than a vapor puff. This phenomenon, and the conditions by which it occurs, needs to be studied and compared with hypothesized calculations and models to determine if the current understanding and modeling methodologies need to be revised.
3. *Aerosol Characteristics*. The nature of the aerosol generated in a large-scale release needs characterization. In particular, the evolution of the vapor to aerosol mass ratio is

unknown for the desired large-scale release conditions of the testing materials, as is the aerosol droplet size and its distribution.

4. *Rainout*. The factors affecting droplet aggregation and precipitation, and the extent to which this occurs, is unknown for large-scale releases, and significantly affects the amount of material available in a cloud and its behavior.

5. *Deposition and Off-gassing*. At the small scale, a TIH released into the environment will have a small amount of interaction with surfaces surrounding the release site, as it is quickly moved and dissipated by the wind. However, at the scale of a railcar release, it is anticipated that the additional and persistent material will experience much more interaction with the surrounding surfaces. The extent to which the material will deposit or permeate into porous surfaces and the subsequent off-gassing rate at the large-scale is unknown.

Although the planning and resources currently do not exist to conduct full-scale 60- or 90-ton releases of the materials of interest, the ECBC/CSAC team planned field test releases for the TSA in the range of one to two tons, configured in such a way as to approximate some of the release conditions and parameters hypothesized to exist at the large scale. Two test gases were used: chlorine and anhydrous ammonia. Chlorine is a TIH of critical concern to TSA, but is difficult to field test in large amounts because of its toxicity, release restrictions, and overall testing costs. Anhydrous ammonia is also a TIH of concern for TSA, but is less problematic to use for large-scale field testing.

A release mechanism was developed for testing to enable the rapid release of the material, consistent with what may be expected during a release from a railcar. Two tons of each material was released in four separate trials into a saucer-shaped containment area. The reason for this configuration was to contain the material in a fixed location during release, thereby limiting the air entrainment rate and energy available to levels consistent with what is expected for large-scale releases. The depression also limited the initial spread of the cloud, additionally reducing the air-entrainment rate and energy influx, and provided a focal area for concentrating instruments to study the initial persistent behavior of the source cloud.

Most trials were conducted under low-wind conditions, with a stable or neutral atmosphere to limit additional turbulence-induced air entrainment and complications. The testing grid contained an array of chemical, physical, and meteorological instrumentation to characterize the various aspects of the releases and gather the data necessary to begin addressing the identified gaps and improving the understanding of the release phenomena.

1.2 Objectives

The objectives of the Jack Rabbit Project Field Tests (Jack Rabbit) were:

1. Execute a reduced-scale test of each of two chemicals (chlorine and anhydrous ammonia) to identify potential vulnerabilities before full test conduct.
2. Develop and evaluate a mechanism for the controlled, rapid release of liquefied, pressurized gases from containment to approximate the conditions hypothesized to generate a persistent vapor-aerosol cloud in a 90-ton railcar release.
3. Characterize the vapor/aerosol cloud movement, behavior, and physiochemical characteristics and compare those characteristics with known observations and testing of large-scale releases of the testing materials.
4. Determine if anhydrous ammonia can potentially act as less expensive and less dangerous dense gas for studying the component phenomena of large scale releases of dense gas TIH materials.
5. Field and evaluate instrumentation that can be used for the study of the large-scale release of the testing materials, and develop and evaluate testing methodology for future additional and potentially larger-scale tests.

1.3 Testing Authority

On 5 November 2009, the U.S. Army Developmental Test Command (DTC), Aberdeen Proving Ground (APG), Maryland, issued a test directive (Appendix A) through the U.S. Army Test and Evaluation Command (ATEC) Decision Support System (ADSS) authorizing West Desert Test Center (WDTC), U.S. Army Dugway Proving Ground (DPG), Utah, to conduct the Jack Rabbit Project, ATEC Project Number 2010-DT-DPG-SNIMT-E5835.[1, 2]

1.4 Test Overview

1.4.1 Basic Design

The design concept of Jack Rabbit was to release large quantities of chlorine and anhydrous ammonia (separate trials) in a depression to satisfy specific test objectives. Chemical, photonic, and meteorological measurements were sampled outside of the depression, and certain measurements were collected within the depression. Full descriptions of the instrumentation are provided in Appendix B.

1.4.2 Scope

The Jack Rabbit was conducted at WDTC, DPG under the direction of the WDTC Meteorology Division with assistance from other WDTC divisions. CSAC provided oversight for the Jack Rabbit.

1.4.3 Relevance

An accidental or intentional release of a TIH material, while in transport via road, rail, water or pipeline, poses a great risk to the life and health of the American public. Through Jack Rabbit, DHS seeks to improve the understanding and modeling of large-scale releases. The vast amount of data collected will provide the foundation for key studies of the cloud source, characteristics, behavior, and movement for years to come. The resulting improvements in emergency response, planning, mitigation, and modeling will ultimately contribute significantly to reducing the risk from large-scale TIH releases in the U.S.

1.4.4 Test Description

Jack Rabbit was conducted at WDTC on the Insensitive Munitions (IM) Test Grid first pilot trial conducted on 07 April 2010 and the last record trial conducted on 21 May 2010. The center of the IM test grid is located at 40.20661577 latitude/-113.2657215 longitude. A 2-m deep depression with a 25-m radius was the focal point of the test. Concentric rings with radii of 50-m, 100-m, 150-m, 200-m, 250-m, 500-m, 1250-m, and 2500-m also had instrumentation deployment. The safety standoff distance was set at 2500-m, and the control point (CP) for test operations was approximately 2835-m from grid center.

Either anhydrous ammonia or chlorine was disseminated during each trial. A single pilot test for each chemical was conducted on 07 and 08 April 2010. These pilot tests consisted of 1-ton disseminations. Upon completion of the pilot trial, adjustments or modifications were made to the instrumentation or testing techniques to obtain the best results during test conduct. Four record trials of each chemical were conducted for a total of eight record trials. Each record trial consisted of a 2-ton release.

WDTC provided meteorological, photonic, and chemical detection instrumentation. Along with the test instrumentation, WDTC designed and constructed a dissemination system, prepared the test site, and procured the chemicals and materials necessary for test conduct.

1.4.5 Test Conduct vs. Objectives Summary

The objectives of the Jack Rabbit are detailed in Section 1.2 of this report. The objectives were addressed as follows:

> **Objective 1** – Satisfied by WDTC successfully executing 10 trials for the Project Jack Rabbit field tests. Two disseminations were 1-ton pilot trials, and eight disseminations were 2-ton record trials.

Objective 2 – Satisfied with the successful design, construction, and operation of a dissemination system built by WDTC. The dissemination system simulated, on a smaller scale, the type of release expected when a 90-ton TIC tanker car is breached. During the trials, the contents of the disseminator evacuated within 60 seconds, as requested by the ECBC/CSAC team.

Objective 3 – Successfully addressed through the deployment of a wide range of instrumentation types to characterize the vapor/aerosol cloud movement, behavior, and physiochemical characteristics. Appendix B, Section 3 of this report discusses the observed chemical clouds from the Jack Rabbit disseminations. Although this section is not intended to be an exhaustive review or analysis of the collected datasets, it satisfies objective stated in Section 1.2.c of this report. The comparison of the data and findings from Jack Rabbit to known observations and testing of large-scale releases will also be performed in follow-on studies in FY 2011 when all datasets have been collected and made available.

Objective 4 – Addressed by conducting the four chlorine and four anhydrous ammonia trials under controlled conditions, allowing a comparison between anhydrous ammonia and chlorine. Additionally, the 1-ton chlorine and anhydrous ammonia pilot tests were conducted on days with nearly identical meteorological conditions. As a result of the field tests, it was determined that utilizing anhydrous ammonia as a surrogate for chlorine in experimentation is complicated by many observed differences in behavior. However, there are individual cloud characteristics of anhydrous ammonia that would allow it to serve as a surrogate for chorine in some cases. Detailed discussion is further continued in Appendix B, Section 3.

Objective 5 – Satisfied by the deployment of many types of photonic, meteorological, and chemical detection instrumentation during the field tests. In some cases, instrumentation was damaged or destroyed because of exposure to high concentrations of chemicals. A better understanding of instrumentation limitations and survivability was achieved through the trials, and improvements in fielding procedures and instrument utilization was documented.

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2.0 TEST DESCRIPTION

2.1 Detailed Test Description

During each trial, chemical releases of chlorine or anhydrous ammonia were made from an elevated disseminator deployed within a 2-m deep and 50-m diameter depression. Point and standoff chemical detection occurred at concentric rings around the dissemination location. Extensive meteorological measurements documented the boundary layer structure over the test grid and surface conditions within the test grid during the trials.

Measurements were taken within the dissemination depression to meet the test objectives of characterizing the vapor/aerosol physiochemical properties of a high concentration chemical release within a semi-confined area. Complete instrumentation descriptions are provided in Appendix C.

Data collection and quality control (QC) of all datasets were the responsibility of the test participant gathering the respective data. WDTC provided the ECBC/CSAC team with pre-test and post-test reports and datasets as described in Table 1.

Table 1. Pre-test and Post-test Reports for the Jack Rabbit Project

TIME FRAME	REPORT/DATASET	PROPOSED DATE
Pre-test	Data Requirements Plan	27 October 2009
	Instrumentation Plan	06 January 2010
	Safety Plan	21 January 2010
	Test Execution Plan (Operations Plan)	28 January 2010
	Climatological Datasets	04 February 2010
	Master Detailed Test Plan	17 March 2010
Post-test	Dissemination Summary	06 June 2010
	DPG[a] Point Detector Datasets	13 June 2010
	DPG Standoff Detector Datasets	13 June 2010
	Meteorological Datasets	13 June 2010
	Photonic Datasets	15 July 2010
	Dense Gas Behavior Assessment Report	15 July 2010
	Field Test Initial Report	15 July 2010
	Downwind Effects Assessment Report	24 July 2010
	Instrumentation Performance Assessment Report	24 July 2010
	Lessons Learned Report	24 July 2010
	Draft Field Test Final Report	24 July 2010
	Field Test Final Report	31 July 2010

[a] U.S. Army Dugway Proving Ground, Utah.

2.1.1 Test Management

Jack Rabbit was conducted at WDTC under the overall direction of the WDTC Meteorology Division, which has extensive experience in conducting field dispersion studies for the Department of Defense (DoD), Washington, DC. WDTC assembled a test team comprised of technical lead personnel from various WDTC divisions and branches. The ECBC/CSAC team was assigned overall program oversight of the Jack Rabbit Project by DHS/TSA.

2.1.2 Data Management

The WDTC Data Sciences Division served as the lead organization for data management and ensured that a quality dataset was collected and permanently archived. The Data Sciences Division assigned a data manager who was responsible for all data time synchronization, QC of datasets, and dataset packaging.

2.1.2.1 Data Collection

Most Jack Rabbit datasets were collected and temporarily archived in real-time. However, several datasets were not accessible in real-time and required data retrieval on a daily basis. The non real-time datasets were collected, reviewed, and temporarily archived every 24 hours. If data collection was terminated on any instrument(s), it was the responsibility of the WDTC test officer (TO) to determine whether that test should continue in the absence of the dataset.

2.1.2.2 Time Stamps

All datasets have a time stamp for each record collected. Time coordinates for all datasets are recorded in Coordinated Universal Time (UTC). Time synchronization was accomplished via global positioning system (GPS) receivers and/or a computer time server whenever possible. If manual time synchronization was necessary, it was done the morning of every test day on every piece of equipment requiring the manual process.

2.1.2.3 QC

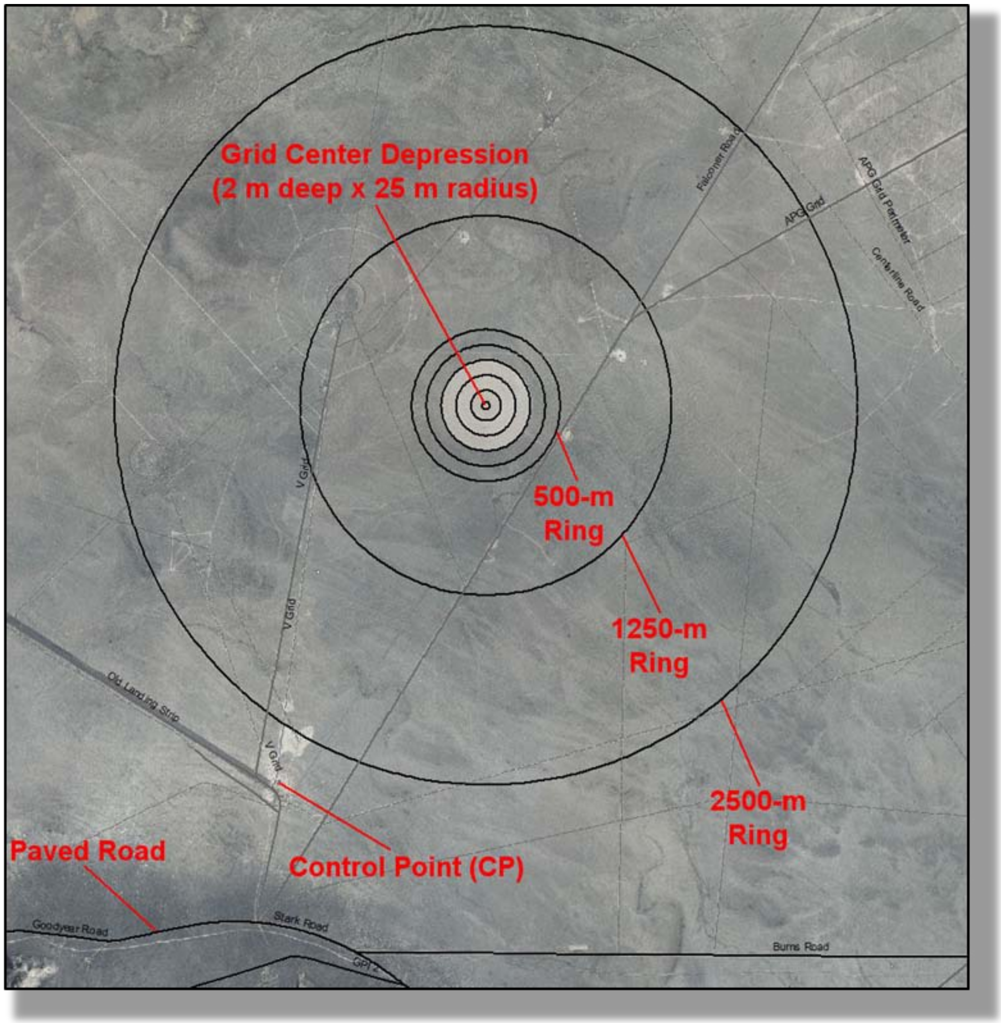
It was the responsibility of the test participants managing their instrumentation to ensure the quality of the collected dataset. Post-test data analysis included error checking and a process to flag bad or suspect data.

2.1.2.4 Data Submission

It was the responsibility of the test participants managing their instrumentation to submit a quality dataset to the TO and data manager as soon as possible after the testing ended. DPG provided ECBC/CSAC with a QC dataset of DPG-collected data on 14 June 2010.

2.1.3 Test Grid

The test grid was located at the WDTC IM Test Grid, which is positioned at 40.20661577 latitude/-113.2657215 longitude. The CP was approximately 2835-m to the south-southwest of grid center. An illustration of the general test area is provided in Figure 1.



NOTE: The dimensions provided for the concentric rings are the radius of the ring, which is also the standoff distance from grid center.

Figure 1. General Area for Jack Rabbit Project Field Tests

The center area of the Jack Rabbit grid was excavated to a depth of 2-m and a radius of 25-m. A technique of "cut and fill" was used for the excavation, which created a berm around the perimeter of the excavated depression. The depression basin had a slope of 1:7 inside the depression and a slope of 1:9 outside the depression. A graphic illustration of the excavated depression is provided in Figure 2.

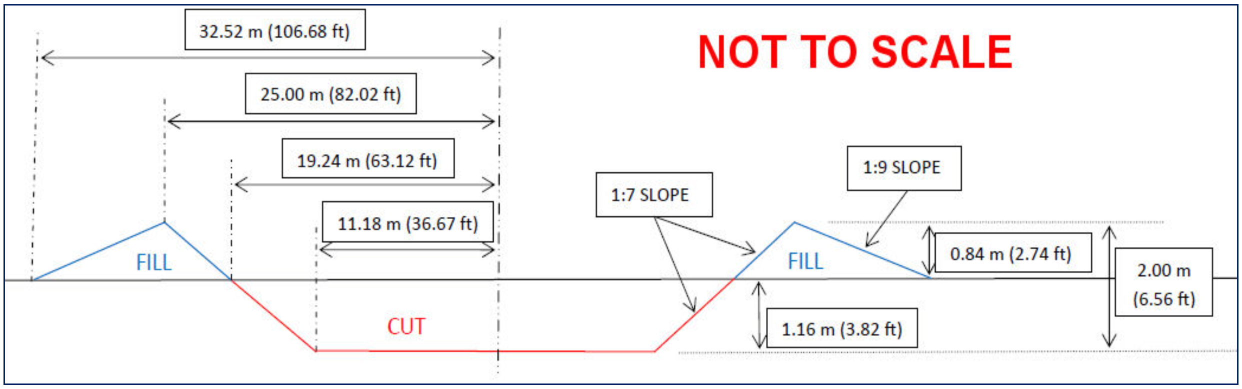


Figure 2. Graphical Depression Depiction of Project Jack Rabbit Project Field Tests

The WDTC Meteorology Division collected meteorological data from the test site over the course of several months. Multi-year climatology from the area surrounding the test site was combined with the test site data to optimize instrument placement and configuration. It was intended that the Jack Rabbit trials be configured to allow for careful study of the release source. The sheltered and low-wind conditions prevalent at the selected site facilitated this, and a 360-degree deployment strategy of the instrumentation was determined to be optimal rigorously interrogate the source and allow testing to proceed regardless wind direction.

Analyses of the testing location additionally confirmed that the best time of day for the desired meteorological conditions was sunrise.

2.1.4 Pre-test Setup

The WDTC Meteorology Division was the lead organization for pre-test setup and ensured that all required documentation and procurement actions were completed and that the test grid was set up in preparation for testing to begin on 07 April 2010. The Test Officer (TO), Mr. Donald Storwold, was responsible for the pre-test setup, either directly or through delegation of duties.

2.1.5 Pre-test Procedures

The following requirements were necessary in advance of the testing in order to proceed with the project: 1) Preparation of National Environmental Policy Act (NEPA) documentation; 2) Operations Security (OPSEC) documentation; 3) preparation of the WDTC Safety Procedures and Risk Assessment, and 4) preparation a WDTC letter of instruction (LOI) for the dissemination system operation.

The TO was responsible for coordinating all activity relating to the Jack Rabbit. This responsibility included notification of the intended test through ADSS and participation in the initial command review (ICR) to inform the WDTC Command of the test project. The TO coordinated scheduling through the WDTC master scheduler and also secured a CP location.

The TO coordinated with the WDTC Safety Office to conduct a pre-operational safety survey (POSS) before testing. Also, before Jack Rabbit testing began, a final command review (FCR) and operational readiness inspection (ORI) were conducted. Before allowing access to the test site, the TO conducted a test orientation and range safety briefing for all test participants.

The TO served as the interface between ECBC/CSAC, the WDTC and DPG Commands, and the Jack Rabbit Test Team. This tasking included the coordination of meetings such as the disseminator preliminary design review (PDR), critical design review (CDR), test readiness review (TRR), instrumentation meetings, and all other test-related meetings.

The TO was responsible for the procurement of all test-related items, including:

1. **Contracts**. WDTC has a contract in place with Jacobs Dugway Team (Dugway, Utah) for test support augmentation. In support of the Jack Rabbit Project field tests, Jacobs provided instrumentation support (mainly bubbler operation/processing), photonic support, data analysis, and portable toilet service at the test site. The TO coordinated with the WDTC contracting officer's representative (COR) for these services.

2. **Supplies**. The project sponsor provided sufficient quantities of the chemicals (chlorine, and anhydrous ammonia) for both the pilot and record test conduct. Additional items included Tyvek® (E.I. du Pont de Nemours and Company, Wilmington, Delaware) protective clothing, sampler tubing, and other miscellaneous test-related items.

3. **Equipment**. Custom disseminator systems were designed and constructed for the Jack Rabbit Project. Purchases for these disseminators included the tanks, valves, and materials for the construction of the stand to mount the disseminator. Other Jack Rabbit Project purchases included bubbler pumps, some communication equipment, personal toxic gas monitors, and Level-B protective clothing for the dissemination crew.

2.1.6 Test Grid Setup

The TO and/or test control officer (TCO) were responsible for the test grid setup, including the following:

1. A metals sweep of the test grid that was conducted before excavation. WDTC surveyed the test grid before and during excavation to ensure proper dimensions of the depression. The test site depression was excavated to the specifications shown in Figure 2.

2. All key test grid points were surveyed, such as photonic support locations, standoff chemical detection locations, point detection locations, and all meteorological locations.

3. WDTC instrumentation: visual spectrum high-definition (HD) cameras, infrared (IR) cameras, Fourier-transform infrared (FTIR) spectrometer, bubblers, Cerex Ultraviolet (UV) Sentry [Cerex Monitoring Solutions, Limited Liability Corporation (LLC), Atlanta, Georgia], Cerex UV Canary [Cerex Monitoring Solutions], Portable Weather Information and Display System (PWIDS), thermocouple array, ultrasonic anemometers, 32-m meteorological towers, 10-m camera towers, and other instrumentation (Appendix B).

4. WDTC provided general test oversight for visiting participants. WDTC also provided oversight for the installation of visiting participant data collection systems. These systems are explained in Table 2.

Table 2. Non-U.S. Army Dugway Proving Ground Participating Organizations and Systems Deployed for the Project Jack Rabbit Field Test

ORGANIZATION	ORGANIZATION LOCATION	DEPLOYED SYSTEM	MANUFACTURER
Signature Science, Limited Liability Corporation (SSLLC)	Austin, Texas	Jaz ultraviolet visible (UV-VIS) sensor	Ocean Optics Inc.; Dunedin, Florida
Center for Toxicology and Environmental Health (CTEH)	Little Rock, Arkansas	AreaRAE (CTEH-owned) and miniRAE (DPG-owned)	RAE® Systems; San Jose, California
SAFER Systems	Camarillo, California	Chemical risk management software	SAFER Systems; Camarillo, California
Air Force Research Laboratory (AFRL)	Tyndall Air Force Base (AFB); Panama City, Florida	Soil core sampling	NA[a]
Naval Surface Warfare Center (NSWC) - Dahlgren	Dahlgren, Virginia	Electronics sampling	NA
METSS Corporation	Westerville, Ohio	Coupon sampling	NA
NSWC - Dahlgren	Dahlgren, Virginia	Hazard prediction modeling	NA
Norwegian Defense Research Establishment	Oslo, Norway	Computational fluid dynamics (CFD) modeling	NA

[a] NA = not applicable

2.1.7 Post-test Procedures

The WDTC Meteorology Division was the lead organization for posttest retrograde. The WDTC TO was responsible for Jack Rabbit post-test retrograde, either directly or through delegation of duties. The following activities occurred at the conclusion of the release trials:

1. *Test Grid.* All Jack Rabbit instrumentation was removed from the test grid. If post-test calibration was necessary for any particular equipment, it was conducted within 48 hours of test conduct completion. All wire, stakes, trash, etc., were removed from the test grid, and the site was restored to its original state as much as possible, except that the WDTC Command decided to leave the depression intact without filling it to its original state.

2. *Test Residue.* All items used in Jack Rabbit Testing were turned in or appropriately disposed of in accordance with (IAW) applicable DPG regulations and permits, as well as federal and state laws. The disseminators used for test conduct were destroyed with high explosive to eliminate the concerns associated with storing hazardous waste.

3. *Shipments.* Test participants requiring shipment of equipment/supplies coordinated this activity through the TO. All shipments occurred within 2 weeks from the time of test completion.

4. *Chemicals.* All leased chemical tanks and cylinders were returned upon the completion of the test. Chemicals were entirely consumed so no unused chemicals needed to be returned to the vendor. This activity was coordinated through the TO.

5. *Control.* Upon completion of all retrograde activities previously outlined, the TO notified the WDTC Command Group and relinquished control of the IM Test Grid area.

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3.0 JACK RABBIT PILOT TEST

3.1 Objective

The objective of the Jack Rabbit pilot tests was to successfully execute a reduced-scale test of two test chemicals (chlorine and anhydrous ammonia) to identify issues and improvements in methodology to be incorporated into test procedures before execution of the full-scale trials.

3.2 Responsibility

The WDTC Meteorology Division was the lead organization for the Jack Rabbit Pilot Test. The TO was responsible for execution of the pilot test, either directly or through delegation of duties (i.e., TCO assignment). All final decisions relating to pilot test execution were the responsibility of the TO.

3.3 Data Analysis/Procedures

The pilot test data were collected and delivered to the ECBC/CSAC team. The end product of the pilot test was photonic, chemical, and meteorological datasets to be used in preparation for the Jack Rabbit Test. Upon review of the datasets, adjustments were made to the instrumentation placement and/or proposed procedure for test conduct.

3.4 Test Procedures

Two trial types were conducted during the pilot test; one chlorine trial and one anhydrous ammonia trial. During the pilot test phase, 1-ton of chlorine and 1-ton of anhydrous ammonia were released in separate trials.

The chlorine disseminator was a modified 500-gal propane tank with a remotely controlled 3-in ball valve assembly mounted to the bottom of the tank. The anhydrous ammonia disseminator was a modified 1,000-gal propane tank with a remotely controlled 4-in ball valve assembly mounted to the bottom of the tank. Both disseminators had an appropriately sized manual knife gate valve mounted between the tank and the remotely controlled valve as a safety precaution.

All disseminations occurred within a 2-m deep × 25-m radius depression located at 40.20661577 latitude/-113.2657215 longitude. The disseminator was mounted on a large metal stand with the outlet of the remotely controlled valve placed at a distance of 2-m above the floor of the depression basin, directed downward. The jet from the disseminator impinged against a 12-ft × 8-ft × 1-in steel plate, which served as the base for the metal disseminator stand.

The order in which the pilot disseminations occurred was the anhydrous ammonia dissemination first (Trial 01-PA), followed by the chlorine dissemination (Trial 02-PC). The dissemination matrix is provided in Table 3.

Table 3. Dissemination Matrix for Jack Rabbit Project Field Test

TEST PHASE	TRIAL NAME[a]	CHEMICAL	QUANTITY	DATE	TIME (UTC)
Pilot Test	01-PA	Anhydrous Ammonia	1 ton	07 April 2010	1400
	02-PC	Chlorine	1 ton	08 April 2010	1345
Record Test	03-RA	Anhydrous Ammonia	2 tons	27 April 2010	1315
	04-RA	Anhydrous Ammonia	2 tons	01 May 2010	1420
	05-RC	Chlorine	2 tons	03 May 2010	1320
	06-RC	Chlorine	2 tons	04 May 2010	1340
	07-RC	Chlorine	2 tons	05 May 2010	1405
	08-RC	Chlorine	2 tons	07 May 2010	1250
	09-RA	Anhydrous Ammonia	2 tons	20 May 2010	1245
	10-RA	Anhydrous Ammonia	2 tons	21 May 2010	1250

[a] Trial names are identified as follows: the first two digits are the trial sequence number, the first letter is the trial type (P = pilot, R = record; the second letter is the chemical type (A = anhydrous ammonia, C = chlorine).

The first pilot test was conducted on 07 April 2010 (anhydrous ammonia pilot test) and the second pilot test (chlorine) was conducted on the following day, 08 April 2010. Operational hours spanned across three different meteorological regimes. The night regime is defined as sunset plus 2 hours to sunrise plus 1 hour, which is approximately 0400 to 1420 UTC [2200 to 0820 Mountain Daylight Time (MDT)]. Morning is defined as sunrise plus 1 hour to sunrise plus 4 hours, which is approximately 1420 to 1720 UTC (0820 to 1120 MDT). Afternoon is defined as sunrise plus 4 hours to sunset minus 1 hour, which is 1720 to 0100 UTC (1120 to 1900 MDT). Disseminations were conducted during the night regime and trial data were collected throughout the morning regime.

Disseminations occurred as close to sunrise as possible because of the meteorological conditions that exist at that time of day. In most cases, wind speeds at the time of dissemination were calm or light with neutral or stable atmospheric conditions. As meteorological regimes cross from one regime to another, calm or light winds often occur, and this phenomenon was used during the test conduct. Disseminating at sunrise provided the daylight needed to record video coverage.

3.5 Data Required

The types of data gathered during the Jack Rabbit pilot test are described in Table 4.

Table 4. Project Jack Rabbit Pilot Test Requirements

ITEM NUMBER	DATA REQUIRED
1	Test control officer (TCO) log
2	Infrared (IR) and visible (VIS) camera data for 3 Dimensional Cloud Analysis and Visualization systems (3DCAV)
3	10-m tower camera data (real time)
4	Berm camera data (real time)
5	Bubbler data collected at the end of the trial (chlorine trials only)
6	Ultraviolet (UV) Canary data [hertz (Hz)] collected at the end of each trial
7	UV Sentry data (chlorine trials only)
8	Fourier-transform infrared (FTIR) data (anhydrous ammonia trials only)
9	Disseminator data (pressure, temperature, valve status, valve inlet pressure, and valve outlet pressure)
10	Thermocouple data (Hz) collected from six heights (real time)
11	Portable Weather Information and Display System (PWIDS) data (real time)
12	Ultrasonic Anemometer data (Hz) collected at the end of the trial

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4.0 JACK RABBIT RECORD TEST

4.1 Objectives

The objectives of the record tests are to execute release trials for each of two chemicals (chlorine and anhydrous ammonia) to accomplish the following objectives:

1. Develop and evaluate a mechanism for the controlled, rapid release of liquefied, pressurized gases from containment to approximate the conditions hypothesized to generate a persistent vapor-aerosol cloud in a 90-ton railcar release.
2. Characterize the vapor/aerosol cloud movement, behavior, and physiochemical characteristics and compare those characteristics with known observations and testing of large-scale releases of the testing materials.
3. Determine if anhydrous ammonia can potentially act as less expensive and less dangerous dense gas for studying the component phenomena of large scale releases of dense gas TIH materials.
4. Field and evaluate instrumentation that can be used for the study of the large-scale release of the testing materials, and develop and evaluate testing methodology for future additional and potentially larger-scale tests.

4.2 Responsibility

The WDTC Meteorology Division was the lead organization for the Record Test. The TO was responsible for the test execution, either directly or through delegation of duties, such as a TCO assignment. All final decisions relating to test conduct were the responsibility of the TO.

4.3 Data Analysis/Procedures

Data were collected and given to the customer for analysis. However, the end product of the Jack Rabbit Record Test was photonic, chemical, and meteorological datasets to be used in the development and evaluation of testing methodologies for future and potentially larger-scale TIC test projects, and in the development and evaluations of algorithms describing TIH behavior.

4.4 Test Procedures

Two trial types were conducted during the record test: four 2-ton chlorine trials and four 2-ton anhydrous ammonia trials. During the record test 8 tons of chlorine and 8 tons of anhydrous ammonia were released in eight separate 2-ton trials.

The chlorine disseminator was a modified 500-gal propane tank with a remotely controlled 3-in ball valve assembly mounted to the bottom of the tank. The anhydrous ammonia disseminator was a modified

1,000-gal propane tank with a remotely controlled 4-in ball valve assembly mounted to the bottom of the tank. Both disseminators had an appropriately sized manual knife gate valve mounted between the tank and the remotely controlled valve as a safety precaution.

All disseminations occurred within a 2-m deep × 25-m radius depression located at 40.20661577 latitude/-113.2657215 longitude. The disseminator was mounted on a large metal stand, with the outlet of the remotely controlled valve placed at a distance of
2-m above the depression basin. The outlet from the remotely controlled valve was 2-m above the depression basin and directed in a downward direction. The jet from the disseminator impinged against a 12-ft × 8-ft × 1-in steel plate, which served as the base for the metal disseminator stand.

The original intent with the dissemination schedule was to conduct the four anhydrous ammonia trials in the first week of testing and then conduct the four chlorine trials in the following week. Inclement weather significantly altered the original plan, so that two anhydrous ammonia trials were conducted, followed by four chlorine trials, and finally, the last two anhydrous ammonia record trials. The resulting dissemination matrix is provided in Table 3.

The record tests began on 27 April 2010 and continued through 21 May 2010. Operational hours spanned across three different meteorological regimes. The night regime is defined as sunset plus 2 hours to sunrise plus 1 hour, which is approximately 0435 to 1320 UTC (2235 to 0720 MDT). Morning is defined as sunrise plus 1 hour to sunrise plus 4 hours, which is approximately 1320 to 1620 UTC (0720 to 1020 MDT). Afternoon is defined as sunrise plus 4 hours to sunset minus 1 hour, which is approximately 1620 to 0135 UTC (1020 to 1935 MDT). Five disseminations occurred in the night regime and three were conducted in the morning regime. However, all of the disseminations were conducted during a period that could be considered a transitional phase, which occurs between regimes.

Disseminations occurred as close to sunrise as possible because of the meteorological conditions that exist at that time of day. In most cases, wind speeds at the time of dissemination were calm or light with neutral or stable atmospheric conditions. As meteorological regimes cross from one regime to another, calm or light winds often occur and this phenomenon was used during the test conduct. Disseminating at sunrise provided the daylight needed to record video coverage.

4.5 Data Required

The types of data gathered during the Jack Rabbit record trials are described in Table 5.

Table 5. Jack Rabbit Project Record Test Requirements

ITEM NUMBER	DATA REQUIRED
1	Test control officer (TCO) log
2	Infrared (IR) and visible (VIS) camera data for 3 Dimensional Cloud Analysis and Visualization systems (3DCAV)
3	10-m tower camera data (real time)
4	Berm camera data (real time)
5	Bubbler data collected at the end of the trial (chlorine trials only)
6	Ultraviolet (UV) Canary data [hertz (Hz)] collected at the end of each trial
7	UV Sentry data (chlorine trials only)
8	Fourier-transform infrared (FTIR) data (anhydrous ammonia trials only)
9	Disseminator data (pressure, temperature, valve status, valve inlet pressure, and valve outlet pressure)
10	Thermocouple data (Hz) collected from six heights (real time)
11	Portable Weather Information and Display System (PWIDS) data (real time)
12	Ultrasonic Anemometer data (Hz) collected at the end of the trial
13	Jaz UV Visible (UV-VIS) data (Hz) recorded in Microsoft® Excel spreadsheet

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5.0 JACK RABBIT DATA

The Jack Rabbit dataset consists of data collected from photonic, chemical, and meteorological instrumentation. Data described within this report pertains to information collected and compiled by DPG only. All other test participant datasets are not addressed in this report.

WDTC manages data collection and distribution with seven levels of data defined.[1] A brief description of the various data categories as follows:

> **Level 1**: Raw data—data in their original form. These are results of field trials, just as recorded.
>
> **Level 2**: Reduced data—data taken from the raw form and consolidated. Invalid or unnecessary data points identified as such with supporting rationale.
>
> **Level 3**: Ordered data—data which have been checked for accuracy and arranged in convenient order for handling. Operations limited to counting and elementary arithmetic.
>
> **Level 4**: Findings or summary statistics—data which have been summarized by elementary mathematical operations. Operations limited to descriptive summaries without judgments or inferences. Does not go beyond what was observed in the test.
>
> **Level 5**: Analysis or inferential statistics—data resulting from statistical test of hypothesis or interval estimation. Execution of planned analysis data includes both comparisons and statistical significance level. Judgments limited to analyst's selection of techniques and significant levels.
>
> **Level 6**: Extended analysis or operations—data resulting from further analytic treatment going beyond primary statistical analysis, combination of analytic results from different sources, or exercise of simulation or models. Judgment limited to analysts' choices only.
>
> **Level 7**: Conclusions or evaluation—data conclusions resulting from applying evaluative military judgments to analytic results.

Data from Jack Rabbit are archived in numerous forms and levels. All data delivered to the customer have passed through a QC process to ensure data integrity. Level 1 data will not be released outside of the WDTC.

The Jack Rabbit dataset continues to grow in size because of ongoing reporting and data compilation efforts. In some cases, the datasets or subsets will elevate in the established levels because of the work being done with the data.

5.1 Trial/Disseminator Information

All Jack Rabbit trial names follow a predetermined format. This format was used in most datasets and will be referred to in future publications and reports relating to the project. The following illustration (Figure 3) provides an explanation of this naming convention.

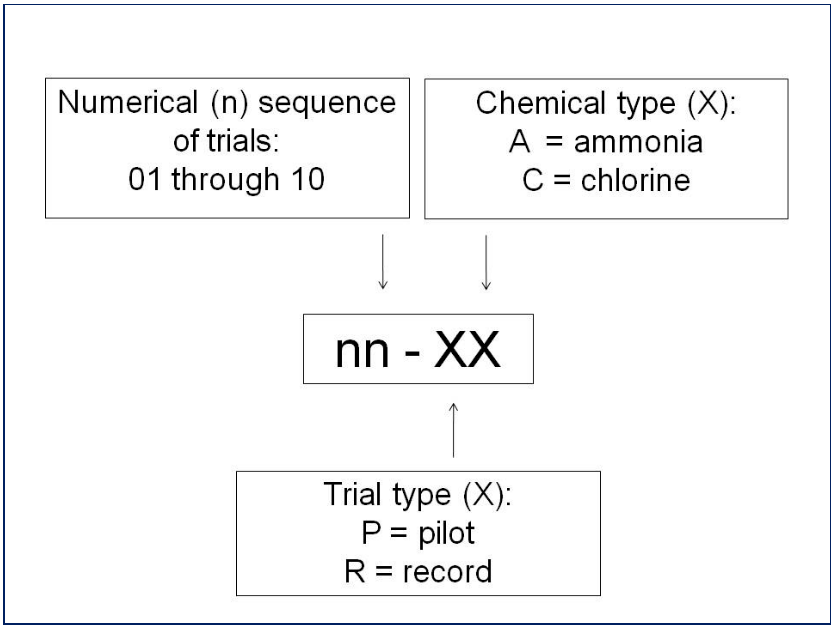

Figure 3. Jack Rabbit Project Field Test File Naming Convention

An example of the Jack Rabbit file naming convention is that “03-RA” represents the third trial, which is a record anhydrous ammonia trial. Trial data collected and/or processed from the field tests are summarized in Table 6.

Table 6. Data Summary for the Jack Rabbit Project

TRIAL NAME[a]	NUMBER OF DATA FILES	NUMBER OF VIDEO FILES	TOTAL NUMBER OF FILES	DATA DATASET SIZE (MB[b])	VIDEO DATASET SIZE (MB)	TOTAL SIZE OF ALL DATASETS (MB)
01-PA	67	199	266	140	200,922	201,062
02-PC	88	150	238	190	260,482	260,672
03-RA	108	246	354	382	37,446	37,828
04-RA	112	444	556	423	86,363	86,786
05-RC	110	172	282	348	155,476	155,824
06-RC	109	207	316	334	146,546	146,880
07-RC	111	237	348	348	243,778	244,126
08-RC	111	285	396	367	304,340	304,707
09-RA	96	350	446	302	450,927	451,229
10-RA	95	300	395	297	381,443	381,740

[a] Trial names are identified as follows: the first two digits are the trial sequence number, the first letter is the trial type (P = pilot, R = record; the second letter is the chemical type (A = anhydrous ammonia, C = chlorine).
[b] Megabyte

In addition to the data displayed in Table 6, there were 2,094 still photograph files created during the field tests for a total of 3.7 gigabytes of data.

Dissemination information from the field tests is summarized in Tables 7 through 16. In these tables, the meteorological data were a 10-second average of all of the 16 tripod-mounted PWIDS on the test grid for the time given. The tank information represents a 5 percent subset of the actual dissemination dataset.

It should be noted that during Trial 10-RA, the disseminator intermittently started and stopped several times at the beginning of the release. The problem did not persist beyond 5 seconds into the dissemination.

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Table 7. Trial 01-PA Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1359:50.6	0.30	27	-0.12	81.43	-3.51	78.88	78.41	-0.455
1359:55.6	ND[c]	ND	ND	ND	ND	78.83	78.42	-0.410
1400:00.6	0.31	27	-0.09	80.90	-3.51	78.73	78.41	-0.425
1400:05.6	ND	ND	ND	ND	ND	72.75	72.51	-0.490
1400:10.6	0.32	20	-0.07	80.29	-3.52	64.59	64.33	-0.535
1400:15.6	ND	ND	ND	ND	ND	58.90	58.63	-0.555
1400:20.6	0.29	22	-0.05	80.05	-3.51	54.88	54.58	-0.725
1400:25.6	ND	ND	ND	ND	ND	52.17	51.83	-0.895
1400:30.6	0.27	21	-0.02	79.97	-3.50	50.04	49.67	-1.140
1400:35.6	ND	ND	ND	ND	ND	48.34	47.93	-5.500
1400:40.6	0.25	24	0.01	79.67	-3.51	46.88	46.45	-8.930
1400:45.6	ND	ND	ND	ND	ND	43.09	42.62	-10.570
1400:50.6	0.24	29	0.03	79.38	-3.51	33.14	32.64	-14.505
1400:55.6	ND	ND	ND	ND	ND	21.54	20.99	-21.040
1401:00.6	0.25	29	0.06	79.14	-3.50	12.53	11.90	-27.190
1401:05.6	ND	ND	ND	ND	ND	5.22	4.54	-34.295
1401:10.6	0.22	35	0.07	79.06	-3.50	1.71	0.99	-38.630
1401:15.6	ND	ND	ND	ND	ND	0.98	0.23	-40.310
1401:20.6	0.21	37	0.11	78.99	-3.47	0.94	0.20	-40.290
1401:25.6	ND	ND	ND	ND	ND	0.96	0.25	-40.095
1401:30.6	0.22	33	0.13	78.58	-3.21	0.97	0.22	-39.985

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 01-PA was conducted on 07 April 2010 at UTC 1400:00.6 (scheduled at UTC 1400) and disseminated 1 ton of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 2 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (P = pilot); the second letter is the chemical type (A = anhydrous ammonia).

Table 8. Trial 02-PC Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1344:49.3	0.64	82	-0.37	74.49	-4.36	63.44	64.42	-1.670
1344:54.3	ND[c]	ND	ND	ND	ND	63.43	64.40	-1.715
1344:59.3	0.64	83	-0.35	74.43	-4.36	63.43	64.40	-1.715
1345:04.3	ND	ND	ND	ND	ND	59.93	60.84	-1.645
1345:09.3	0.65	83	-0.34	74.37	-4.36	54.09	54.84	-1.650
1345:14.3	ND	ND	ND	ND	ND	49.49	50.09	-1.595
1345:19.3	0.64	83	-0.32	74.38	-4.34	45.85	46.30	-1.595
1345:24.3	ND	ND	ND	ND	ND	42.78	43.06	-1.645
1345:29.3	0.60	83	-0.32	74.40	-4.33	40.63	40.88	-1.665
1345:34.3	ND	ND	ND	ND	ND	38.83	39.05	-1.665
1345:39.3	0.58	84	-0.30	74.38	-4.32	37.50	37.74	-1.630
1345:44.3	ND	ND	ND	ND	ND	36.46	36.68	-2.850
1345:49.3	0.58	84	-0.29	74.36	-4.31	33.25	33.44	-5.010
1345:54.3	ND	ND	ND	ND	ND	25.08	25.17	-10.020
1345:59.3	0.57	85	-0.27	74.31	-4.31	16.53	16.55	-20.245
1346:04.3	ND	ND	ND	ND	ND	9.11	9.06	-33.620
1346:09.3	0.57	85	-0.26	74.24	-4.30	4.04	3.92	-43.470
1346:14.3	ND	ND	ND	ND	ND	1.45	1.27	-48.770
1346:19.3	0.56	90	-0.25	74.28	-4.28	0.75	0.58	-50.495
1346:24.3	ND	ND	ND	ND	ND	0.72	0.55	-49.540
1346:29.3	0.54	91	-0.25	74.30	-4.28	0.70	0.59	-50.840

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 02-PC was conducted on 08 April 2010 at UTC 1344:59.3 (scheduled at UTC 1400) and disseminated 1 Ton of chlorine with a valve body diameter of 3 inches and a valve outlet diameter of 1.5 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (P = pilot); the second letter is the chemical type (C = chlorine)

Table 9. Trial 03-RA Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1314:50.9	1.25	327	7.42	56.19	-0.76	117.71	118.18	11.060
1314:55.9	ND[c]	ND	ND	ND	ND	117.71	118.18	11.055
1315:00.9	1.25	328	7.43	56.22	-0.74	117.71	118.18	11.075
1315:05.9	ND	ND	ND	ND	ND	103.61	104.03	11.130
1315:10.9	1.23	330	7.41	56.09	-0.79	87.69	88.11	11.125
1315:15.9	ND	ND	ND	ND	ND	82.21	82.58	11.125
1315:20.9	1.26	330	7.44	56.07	-0.77	81.37	81.72	11.110
1315:25.9	ND	ND	ND	ND	ND	80.12	80.43	10.885
1315:30.9	1.28	331	7.44	55.95	-0.80	79.06	79.35	10.585
1315:35.9	ND	ND	ND	ND	ND	78.15	78.42	10.485
1315:40.9	1.28	332	7.45	55.98	-0.78	77.16	77.40	10.355
1315:45.9	ND	ND	ND	ND	ND	76.19	76.39	10.120
1315:50.9	1.30	333	7.46	55.90	-0.79	75.15	75.32	9.805
1315:55.9	ND	ND	ND	ND	ND	74.17	74.33	9.745
1316:00.9	1.30	333	7.47	55.80	-0.81	72.98	73.12	9.390
1316:05.9	ND	ND	ND	ND	ND	71.76	71.87	9.040
1316:10.9	1.31	334	7.50	55.87	-0.77	70.42	70.48	8.785
1316:15.9	ND	ND	ND	ND	ND	69.01	69.05	4.975
1316:20.9	1.29	334	7.49	55.75	-0.80	67.19	67.19	2.560
1316:25.9	ND	ND	ND	ND	ND	63.64	63.60	1.295
1316:30.9	1.29	335	7.51	55.78	-0.78	52.43	52.32	-1.950
1316:35.9	ND	ND	ND	ND	ND	35.65	35.56	-8.685
1316:40.9	1.28	336	7.51	55.72	-0.79	21.12	20.91	-16.940
1316:45.9	ND	ND	ND	ND	ND	10.48	10.25	-24.790

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 03-RA was conducted on 27 April 2010 at UTC 1315:00.9 (scheduled at UTC 1315) and disseminated 2 Tons of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 2 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (A = anhydrous ammonia)

Table 9. Trial 03-RA Dissemination Summary for Jack Rabbit Project (cont)

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1316:50.9	1.29	337	7.54	55.86	-0.73	3.51	3.16	-32.675
1316:55.9	ND[c]	ND	ND	ND	ND	0.67	0.33	-37.330
1317:00.9	1.28	337	7.53	55.80	-0.75	0.28	-0.05	-38.500

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 03-RA was conducted on 27 April 2010 at UTC 1315:00.9 (scheduled at UTC 1315) and disseminated 2 Tons of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 2 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (A = anhydrous ammonia)

Table 10. Trial 04-RA Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1419:50.7	1.52	248	5.79	53.42	-2.95	99.29	99.99	5.205
1419:55.7	ND[c]	ND	ND	ND	ND	99.29	99.98	5.200
1420:00.7	1.49	253	5.80	53.41	-2.95	99.29	99.99	5.195
1420:05.7	ND	ND	ND	ND	ND	86.32	87.04	5.130
1420:10.7	1.39	254	5.80	53.54	-2.92	71.94	72.55	5.190
1420:15.7	ND	ND	ND	ND	ND	65.90	66.49	5.170
1420:20.7	1.43	256	5.79	53.45	-2.94	62.33	62.86	5.115
1420:25.7	ND	ND	ND	ND	ND	60.48	61.00	5.145
1420:30.7	1.42	255	5.79	53.37	-2.97	59.41	59.91	5.010
1420:35.7	ND	ND	ND	ND	ND	58.81	59.28	4.700
1420:40.7	1.41	258	5.79	53.43	-2.96	58.26	58.70	4.840
1420:45.7	ND	ND	ND	ND	ND	57.67	58.08	4.840
1420:50.7	1.43	255	5.79	53.55	-2.92	57.12	57.52	4.615
1420:55.7	ND	ND	ND	ND	ND	56.48	56.84	4.365
1421:00.7	1.39	256	5.79	53.43	-2.95	55.84	56.18	3.800
1421:05.7	ND	ND	ND	ND	ND	55.12	55.43	4.010
1421:10.7	1.36	258	5.80	53.47	-2.94	54.39	54.67	3.700
1421:15.7	ND	ND	ND	ND	ND	53.56	53.81	-0.320
1421:20.7	1.40	256	5.81	53.51	-2.92	52.61	52.83	-4.865
1421:25.7	ND	ND	ND	ND	ND	51.35	51.50	-5.250
1421:30.7	1.43	254	5.80	53.42	-2.94	44.87	45.02	-7.015
1421:35.7	ND	ND	ND	ND	ND	32.23	32.25	-12.450
1421:40.7	1.43	257	5.80	53.67	-2.88	19.22	19.23	-19.930
1421:45.7	ND	ND	ND	ND	ND	9.73	9.67	-26.865

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 04-RA was conducted on 01 May 2010 at UTC 1420:00.7 (scheduled at UTC 1420) and disseminated 2 Tons of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 2 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (A = anhydrous ammonia)

Table 10. Trial 04-RA Dissemination Summary for Jack Rabbit Project (cont)

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1421:50.7	1.55	261	5.81	53.76	-2.85	3.17	3.09	-33.860
1421:55.7	ND[c]	ND	ND	ND	ND	0.42	0.34	-37.960
1422:00.7	1.61	262	5.83	53.64	-2.86	0.06	-0.04	-38.805

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 04-PA was conducted on 01 May 2010 at UTC 1420:00.7 (scheduled at UTC 1420) and disseminated 2 Tons of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 2 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (A = anhydrous ammonia)

Table 11. Trial 05-RC Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1319:50.2	1.49	343	3.54	55.30	-4.59	51.26	51.89	1.955
1319:55.2	ND[c]	ND	ND	ND	ND	51.28	51.90	1.955
1320:00.2	1.55	344	3.54	55.15	-4.63	51.27	51.90	1.920
1320:05.2	ND	ND	ND	ND	ND	43.52	44.13	1.900
1320:10.2	1.56	344	3.53	55.15	-4.64	40.05	40.67	1.985
1320:15.2	ND	ND	ND	ND	ND	39.49	40.10	2.010
1320:20.2	1.58	344	3.53	55.11	-4.65	38.89	39.51	1.515
1320:25.2	ND	ND	ND	ND	ND	38.42	39.02	1.330
1320:30.2	1.60	346	3.53	55.06	-4.66	37.54	38.15	0.995
1320:35.2	ND	ND	ND	ND	ND	36.31	36.91	0.260
1320:40.2	1.65	346	3.52	55.06	-4.67	34.73	35.33	-0.070
1320:45.2	ND	ND	ND	ND	ND	33.04	33.63	-0.245
1320:50.2	1.59	347	3.52	55.16	-4.65	31.38	31.96	-1.185
1320:55.2	ND	ND	ND	ND	ND	23.23	23.68	-8.690
1321:00.2	1.64	347	3.52	55.01	-4.69	6.80	7.13	-24.080
1321:05.2	ND	ND	ND	ND	ND	0.27	0.44	-36.505
1321:10.2	1.63	348	3.51	54.94	-4.71	0.02	0.21	-37.230
1321:15.2	ND	ND	ND	ND	ND	0.02	0.20	-37.460
1321:20.2	1.58	348	3.49	55.06	-4.69	0.02	0.22	-37.860

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 05-RC was conducted on 03 May 2010 at UTC 1320:00.2 (scheduled at UTC 1320) and disseminated 2 tons of chlorine with a valve body diameter of 3 inches and a valve outlet diameter of 3 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (C = chlorine)

Table 12. Trial 06-RC Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1339:51.2	6.09	18	6.13	38.75	-6.90	51.43	52.03	5.740
1339:56.2	ND[c]	ND	ND	ND	ND	51.42	52.03	5.810
1340:01.2	6.07	19	6.13	38.71	-6.90	51.44	52.03	5.800
1340:06.2	ND	ND	ND	ND	ND	45.46	46.04	5.755
1340:11.2	6.46	21	6.14	38.58	-6.94	44.78	45.35	5.760
1340:16.2	ND	ND	ND	ND	ND	43.52	44.07	5.670
1340:21.2	6.40	20	6.14	38.50	-6.96	42.42	42.99	4.630
1340:26.2	ND	ND	ND	ND	ND	41.99	42.55	4.805
1340:31.2	6.33	18	6.14	38.51	-6.96	41.21	41.78	4.240
1340:36.2	ND	ND	ND	ND	ND	39.49	40.03	3.730
1340:41.2	6.13	20	6.16	38.57	-6.93	37.47	38.02	3.395
1340:46.2	ND	ND	ND	ND	ND	35.43	35.98	2.450
1340:51.2	6.31	21	6.16	38.53	-6.94	24.56	25.03	-6.760
1340:56.2	ND	ND	ND	ND	ND	6.64	6.92	-21.510
1341:01.2	6.07	21	6.16	38.50	-6.94	0.21	0.36	-35.455
1341:06.2	ND	ND	ND	ND	ND	0.04	0.21	-36.940
1341:11.2	6.25	21	6.17	38.43	-6.96	0.04	0.19	-37.065

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 06-RC was conducted on 04 May 2010 at UTC 1340:01.2 (scheduled at UTC 1340) and disseminated 2 tons of chlorine with a valve body diameter of 3 inches and a valve outlet diameter of 3 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (C = chlorine)

Table 13. Trial 07-RC Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1404:50.5	1.54	235	6.24	30.90	-9.71	53.75	56.25	3.640
1404:55.5	ND[c]	ND	ND	ND	ND	53.75	56.24	3.570
1405:00.5	1.45	235	6.24	30.73	-9.77	53.76	56.23	3.655
1405:05.5	ND	ND	ND	ND	ND	44.98	47.40	3.585
1405:10.5	1.46	234	6.24	30.79	-9.75	41.24	43.48	3.645
1405:15.5	ND	ND	ND	ND	ND	41.31	43.17	3.625
1405:20.5	1.47	235	6.25	30.81	-9.73	40.68	42.20	3.315
1405:25.5	ND	ND	ND	ND	ND	40.52	41.29	2.620
1405:30.5	1.45	232	6.27	30.77	-9.73	39.58	40.14	2.280
1405:35.5	ND	ND	ND	ND	ND	38.10	38.65	2.115
1405:40.5	1.37	230	6.28	30.67	-9.77	36.54	37.09	1.535
1405:45.5	ND	ND	ND	ND	ND	35.04	35.59	1.520
1405:50.5	1.31	229	6.29	30.69	-9.75	33.28	33.82	0.715
1405:55.5	ND	ND	ND	ND	ND	24.19	24.65	-7.475
1406:00.5	1.24	227	6.30	30.70	-9.74	7.32	7.61	-23.705
1406:05.5	ND	ND	ND	ND	ND	0.36	0.51	-35.565
1406:10.5	1.19	227	6.32	30.73	-9.71	0.02	0.19	-37.390

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 07-RC was conducted on 05 May 2010 at UTC 1405:00.5 (scheduled at UTC 1405) and disseminated 2 tons of chlorine with a valve body diameter of 3 inches and a valve outlet diameter of 3 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (C = chlorine)

Table 14. Trial 08-RC Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1249:52.4	1.13	162	-2.79	59.23	-9.66	49.30	50.29	0.015
1249:57.4	ND[c]	ND	ND	ND	ND	49.30	50.29	0.055
1250:02.4	1.12	162	-2.80	59.27	-9.66	49.30	50.29	0.040
1250:07.4	ND	ND	ND	ND	ND	41.53	42.39	0.265
1250:12.4	1.21	161	-2.82	59.32	-9.67	36.66	37.53	0.470
1250:17.4	ND	ND	ND	ND	ND	36.00	36.87	0.510
1250:22.4	1.20	161	-2.84	59.35	-9.68	35.71	36.57	0.340
1250:27.4	ND	ND	ND	ND	ND	35.28	36.14	-0.600
1250:32.4	1.19	160	-2.86	59.41	-9.69	34.39	35.26	-0.605
1250:37.4	ND	ND	ND	ND	ND	33.41	34.27	-0.735
1250:42.4	1.18	160	-2.87	59.42	-9.70	32.56	33.42	-0.910
1250:47.4	ND	ND	ND	ND	ND	31.56	32.41	-1.465
1250:52.4	1.25	160	-2.90	59.49	-9.71	29.97	30.81	-1.575
1250:57.4	ND	ND	ND	ND	ND	26.32	27.11	-5.945
1251:02.4	1.20	161	-2.91	59.49	-9.72	12.23	12.87	-15.480
1251:07.4	ND	ND	ND	ND	ND	1.52	2.06	-31.755
1251:12.4	1.20	161	-2.93	59.57	-9.72	0.04	0.57	-37.025
1251:17.4	ND	ND	ND	ND	ND	0.02	0.51	-37.680
1251:22.4	1.17	160	-2.94	59.64	-9.72	0.02	0.52	-37.810

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 08-RC was conducted on 07 May 2010 at UTC 1250:02.4 (scheduled at UTC 1250) and disseminated 2 tons of chlorine with a valve body diameter of 3 inches and a valve outlet diameter of 3 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (C = chlorine)

Table 15. Trial 09-RA Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1244:51.2	1.29	73	10.66	68.85	5.17	121.74	122.39	16.090
1244:56.2	ND[c]	ND	ND	ND	ND	121.73	122.40	16.050
1245:01.2	1.30	61	10.66	68.94	5.19	121.73	122.40	16.065
1245:06.2	ND	ND	ND	ND	ND	88.63	89.23	16.075
1245:11.2	1.38	62	10.66	68.90	5.19	81.22	81.78	16.025
1245:16.2	ND	ND	ND	ND	ND	78.96	79.40	15.560
1245:21.2	1.54	56	10.68	68.92	5.20	75.42	75.79	14.225
1245:26.2	ND	ND	ND	ND	ND	71.34	71.62	13.210
1245:31.2	1.62	51	10.69	68.92	5.22	60.51	60.78	5.665
1245:36.2	ND	ND	ND	ND	ND	29.08	29.29	-4.815
1245:41.2	1.73	46	10.68	68.98	5.22	4.65	4.62	-24.210
1245:46.2	ND	ND	ND	ND	ND	0.15	-0.03	-32.995
1245:51.2	1.80	38	10.69	69.04	5.24	0.04	-0.14	-33.750

[a] Coordinated universal time

[b] Pounds per square inch

[c] No data

NOTES: 1. Trial 09-RA was conducted on 20 May 2010 at UTC 1245:01.2 (scheduled at UTC 1245) and disseminated 2 tons of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 4 inches.

2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (C = chlorine)

Table 16. Trial 10-RA Dissemination Summary for Jack Rabbit Project

TIME (UTC[a])	WIND SPEED (M/S)	WIND DIRECTION	TEMPERATURE (°C)	RELATIVE HUMIDITY	DEW POINT (°C)	TANK VAPOR PRESSURE (PSI[b])	TANK LIQUID PRESSURE (PSI)	TANK TEMPERATURE (°C)
1249:51.2	3.47	289	8.11	55.46	-0.28	91.85	92.65	16.560
1249:56.2	ND[c]	ND	ND	ND	ND	91.85	92.65	16.645
1250:01.2	3.52	289	8.12	55.67	-0.22	91.85	92.65	16.650
1250:06.0	ND	ND	ND	ND	ND	75.34	76.15	16.765
1250:11.0	3.53	291	8.12	55.37	-0.29	76.44	77.14	17.005
1250:16.0	ND	ND	ND	ND	ND	76.17	76.78	16.350
1250:21.0	3.70	291	8.11	55.24	-0.34	74.65	75.18	15.635
1250:26.0	ND	ND	ND	ND	ND	72.68	73.13	15.015
1250:31.0	3.43	291	8.11	55.37	-0.31	70.11	70.48	14.280
1250:36.0	ND	ND	ND	ND	ND	66.62	66.92	12.890
1250:41.0	3.23	289	8.11	55.58	-0.25	56.48	56.74	8.895
1250:46.0	ND	ND	ND	ND	ND	27.34	27.49	-2.880
1250:51.0	3.43	289	8.11	55.54	-0.26	4.77	4.73	-21.190
1250:56.0	ND	ND	ND	ND	ND	0.09	-0.03	-30.725
1251:01.0	3.43	290	8.11	55.48	-0.28	0.01	-0.10	-31.400

[a] Coordinated universal time
[b] Pounds per square inch
[c] No data

NOTES: 1. Trial 10-RA was conducted on 21 May 2010 at UTC 1250:01.2 (scheduled at UTC 1250) and disseminated 2 tons of anhydrous ammonia with a valve body diameter of 4 inches and a valve outlet diameter of 4 inches.
2. Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (R = record); the second letter is the chemical type (A = anhydrous ammonia)

6.0 Dense Gas Behavior Assessment

This section provides documentation of the observations of dense gas behavior of the chemicals disseminated (anhydrous ammonia and chlorine) during the Jack Rabbit trials. This report is not intended to be an exhaustive review or analysis of the collected datasets. Comprehensive studies and analyses will be conducted through additional follow-on tasks which are planned to begin in FY 2011 when all datasets have been collected and made available.

6.1 Trial Observations

The two gases used in this experiment are known to exhibit dense gas behavior upon release from pressurized containment. This is due to the cooling of the gas as it is forced through the opening in containment, a process known as the Joule-Thomson effect, making it much denser than the surrounding ambient air.[a] Chlorine additionally is denser than air by nature of its molecular mass being approximately 2.4 times higher than that of the average air composition. Consequently, these gases in most cases will slump to the ground upon release and tend to collect in low lying areas. Understanding this behavior and its variances for each of the toxic gases of concern is of great importance for models attempting to account for this phase of a release scenario.

Each of the pilot tests and record trials are shown in Table 17 with the wind speed and relative humidity at the time of the release. For the trial number, the first 2 numerals represent the overall ordered number of the release, the next letter represents whether the release was a pilot test (P) or a record test (R), and the last letter represents whether anhydrous ammonia (A) or chlorine (C) was released.

Table 17. Wind Speed and Relative Humidity for Each Jack Rabbit Trial

TRIAL NUMBER	WIND SPEED (m/s)	RELATIVE HUMIDITY
01-PA	0.25	80%
02-PC	0.6	75%
03-RA	1.3	55%
04-RA	1.4	55%
05-RC	1.6	55%
06-RC	6.2	40%
07-RC	1.3	30%
08-RC	1.2	60%
09-RA	1.5	70%
10-RA	3.5	55%

[a] A. W. Adamson (1973). "Chapter 4 – Chemical thermodynamics. The First Law of Thermodynamics". *A textbook of Physical Chemistry* (1st ed.). Academic press.

6.1.1 Ammonia Observations

For the anhydrous ammonia releases, in general it was observed that upon release a billowing white cloud front was created that was propelled outward in all directions from the tank by the force of the escaping gas (Figure 4). The white cloud was attributed to condensed water vapor generated by humidity present in the ambient air coming into contact with very cold anhydrous ammonia gas. Although anhydrous ammonia gas is invisible itself, the condensed water vapor served as a good indicator as to the location and behavior of the cloud.

Figure 4. Trial 01-PA at T = +2 Seconds

In each of the cases with lower wind speeds (01-PA, 03-RA, 04-RA and 09-RA), the cloud rapidly engulfed the tank and expanded radially beyond the borders of the 50-m diameter depression basin, with the cloud front reaching a height of approximately 5-m. The radial spreading appeared to extend to a diameter of over 100 meters and flatten out as it vertically slumped after the termination of the release, consistent with expectations of a dense gas (Figure 5).

Figure 5. Trial 01-PA at T = +1 Minute

In the case of the pilot test with very low winds (01-PA), the anhydrous ammonia formed a seemingly symmetrical 1-meter high cloud around the release site, which persisted for approximately 45 minutes before slowly dissipating vertically to 150-m and above, as measured by stand-off scanning UV Sentry instruments. Additionally it was noted in the pilot test that a rising dome of the cloud began to form directly over the tank immediately after the termination of the release, which continued for approximately 15 minutes (Figure 6).

Figure 6. Trial 01-PA at T = +2 Minutes

The dome reached a height and diameter of approximately 15 meters, and was attributed to boiling liquid anhydrous ammonia that had collected beneath the tank, which was secondarily contributing to the cloud formation after the release had been completed. This cloud in the dome appeared to be rising in the center to its top before spreading radially and slumping down all sides until it was at the same level as the remainder of the cloud (approximately 1 meter high). Visible off-gassing coming from the basin was noted to last until approximately 60 minutes after the beginning of the release.

This cloud dome-building effect was not noted in the record anhydrous ammonia trials (03-RA, 04-RA, 09-RA, and 10-RA), possibly due to the higher wind speeds shearing the top of the forming cloud before it was allowed to build vertically. However, in these cases, a substantial amount of additional cloud formation could be seen coming from the bottom of the depression basin after the termination of the release and drifting away with the wind for approximately 15 minutes. This was also attributed to liquid anhydrous ammonia vaporizing and residual material off-gassing from the soil in which it had become trapped.

The final anhydrous ammonia trial (10-RA) was conducted with the highest winds of any of the anhydrous ammonia trials, and resulted in a rapidly dispersed cloud which was swept from the depression basin as soon as it was formed. The cloud was observed to immediately be carried off with the wind as it was being generated and rapidly mixing with the air to reach a height of approximately 10 meters upon leaving the depression basin. This trial did produce the most persistent visible off-gassing phase, which was observed to last for approximately 5 hours after the dissemination. This extended off-gassing phase was likely influenced by saturation of the ground with anhydrous ammonia from the previous 09-RA trial, along with a large amount of water present in the soil due to recent rain showers.

6.1.2 Chlorine Observations

For the chlorine releases, in general it was observed that upon release a billowing green-yellow cloud was created in the first few seconds that was propelled outward in all directions from the tank by the force of the escaping gas (Figure 7). The fluffy characteristic of the cloud was attributed to condensed water vapor generated by humidity present in the ambient air coming into contact with the very cold chlorine gas. The color of the cloud is a result of the characteristic green-yellow color of chlorine vapor. The condensed water vapor was a good indicator as to the location and behavior of the cloud, but chlorine vapor (absent of any condensed water vapor) was also visible in the form of transparent green-yellow vapor and provided further definition of the extent of the chlorine cloud. The chlorine pilot test (02-PC) was conducted under the lowest wind conditions (nearly calm at 0.25 m/s) and represents a clear view of the cloud behavior being driven by dense gas effects. The cloud generated from the release expanded to fill the depression basin, but did not obscure the tank during or after the release (Figure 8).

Figure 7. Trial 02-PC at T = +2 Seconds

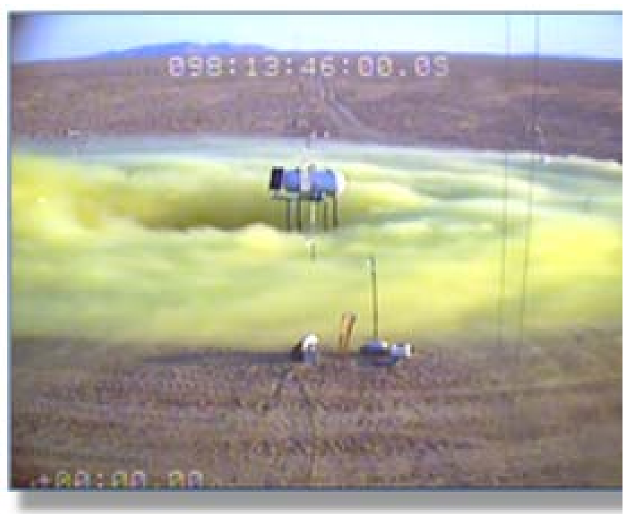

Figure 8. Trial 02-PC at T = +1 Minute

During the release, the cloud depth inside the depression basin was approximately 2 meters, and only small amounts of the visible cloud could be seen escaping the confines of the basin.

After the termination of the release, the chlorine cloud seemingly appeared to behave as a fluid, filling the 50-m diameter basin and slowly "sloshing" around as a liquid does in a bowl (Figure 9).

Figure 9. Trial 02-PC at T = +4 Minutes

The small amount of measurable winds present pushed small waves of material westward and small amounts of the chlorine over the edge of the depression basin. Chlorine escaping the depression basin remained very close to the ground, not exceeding approximately 0.1 meters in height. The portion of the cloud that was not transparent, attributed to condensed water vapor, became lighter in color over time was visible for a total of approximately 25 minutes before becoming transparent. After 25 minutes, green-yellow transparent chlorine vapor was still visible in the bottom of the depression basin, which persisted for an additional 15 minutes until the wind speed picked up to approximately 1 m/s and carried the last remaining visible vapor away to the west. After the visible chlorine vapor was completely absent, a small, white plume could be seen evolving from the water puddles present in the depression basin from recent rains. The puddles were frozen to a white solid as either ice or a chlorine-hydrate species. There was also visible white solid frosting which could be seen covering the steel plate and on the legs of the cradle beneath the release tank. The wispy white plume was thought to possibly be ammonium chloride which is known to form spontaneously in the air when anhydrous ammonia and chlorine or hydrogen chloride gases interact. Given that the odor of anhydrous ammonia could be detected evolving from the ground before trial 02-PC due to the anhydrous ammonia trial the previous day (01-PA), this was considered the likely source by subject-matter experts discussing the subject at the Jack Rabbit command post. The white plume was observed until approximately 1.5 hours after the release.

For the record chorine trials, there were 3 releases that were conducted under low wind conditions between 1.2 – 1.6 m/s (05-RC, 07-RC, and 08-RC). For these trials, the cloud could be seen spreading radially in all directions during the release, with the momentum of the escaping jet propelling even into the direction of the wind up to the edge of the depression basin. The escaping chlorine was observed to form green-yellow fluffy cloud which was non-transparent due to condensing water vapor. The degree to which the condensed water vapor was observable in the cloud seemed to be related to the humidity – trials with higher relative humidity resulted in greater observable amounts of condensed water vapor that was generated upon interaction with the cold chlorine vapor.

In general for release 05-RC, 07-RC, and 08-RC, it was observed that a significant portion of the visible cloud escaped the confines of the basin during the release and was carried away with the wind that was present. This portion of the cloud remained at a height of 1 – 2 meters as it traveled with the wind, became transparent, and retained its green-yellow visible appearance for at least 0.5 to 1 kilometer away from the tank. A persistent chlorine cloud also remained in the basin however, which was observed to generally last for approximately 15-20 minutes before being stripped away and carried downwind. During this time several energetic anomalous eruptions were observed to unexpectedly occur, which will be discussed in section 1.2.3 below.

One trial (06-RC) was conducted under relatively high wind conditions (6.2 m/s). Although the Jack Rabbit trials were intended to be conducted in low wind conditions (< 2 m/s), unexpectedly changing weather yielded much higher winds on the day of the test. Due to facts that the testing team was already activated for the day, the instruments were deployed, and the large majority of the expense of the trial had already been incurred, it was decided to proceed with the test despite the higher winds.

Due to the high winds, there was little evidence of dense gas behavior in trial 06-RC since the chlorine cloud was immediately captured and mixed with the wind as soon as it escaped the tank. Although the escaping jet still managed to initially propel the chlorine cloud in all directions, it only traveled a few feet upwind before being swept away out of the basin and downwind (Figure 10).

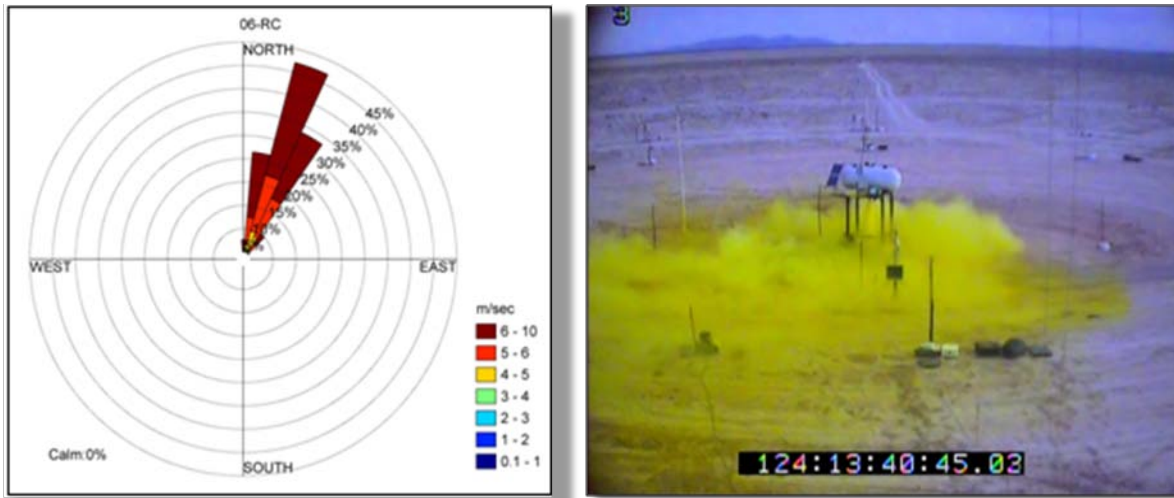

Figure 10. Trial 06-RC Wind Rose Graph and South Tower Photograph at +45 Seconds After Dissemination

As the cloud rapidly mixed with air, there was little observable condensed water vapor present for very long, and an extended narrow plume of the material could be seen extending from the tank downwind for the duration of the release. Upon termination of the release, the chlorine was all immediately swept from the basin and carried downwind. The cloud was estimated to be dozens of meters high and could be seen as a green-yellow vapor at least 4 kilometers away from the release site.

6.1.3 Anomalous Eruptions

During each of the record chorine trials 05-RC, 06-RC, 07-RC, and 08-RC, and to a lesser extent during the chorine pilot test 02-PC, spontaneous energetic eruptions of gas could be observed occurring from the bottom of the release basin, beginning approximately 3 minutes after each release.

The eruptions were very forceful, ejecting clouds of chlorine up to 15 meters high, which then immediately slumped back down into the basin as a dense gas (Figure 11). Subsequent inspection of the basin revealed numerous shallow craters in the soil, and the steel plate below the tank covered in dirt. Larger eruptions were observed roughly every 10 -15 seconds, and the duration of this phenomenon was approximately 30 minutes for each trial for the visible effects. It should be noted however that technicians who approached the basin 2 hours after the release reported hearing continuous “crackling and popping noises” coming from the basin.

Figure 11. Eruption Observed During Trial 05-RC

Initial thoughts as to the origin of the eruptions focused on the potential that a chemical reaction had occurred between the chlorine and residual anhydrous ammonia from previous tests, resulting in an unstable product – nitrogen trichloride. This substance is a very sensitive yellow liquid explosive that will spontaneously detonate after being generated. However, because the eruptions continued to occur at apparently the same intensity throughout all of the chlorine trials, it was determined that it was unlikely that this reaction and product were the cause of the events. It would be expected that a decreasing intensity and frequency of the eruptions would occur on later trials, as residual anhydrous ammonia present in the soil would have been consumed and less available.

A definitive conclusion as to the nature of the eruptions cannot be derived at this point because instrumentation and experiments were not deployed in such a way to study the unexpected phenomenon. However, based upon discussions with subject-matter experts and previous reporting from releases of liquefied natural gas, it was determined that the most likely cause of the eruptions was a phenomenon known as rapid phase transition (RPT). An RPT is the rapid, spontaneous conversion of a liquid to vapor, occurring as a result of heat gained from the surface. The vapor is generated very rapidly, creating localized overpressures which look like explosive events. [b]

The RPT events were not observed for any of the anhydrous ammonia releases. This may be attributable to the fact that anhydrous ammonia has a high affinity for water, and for each trial the soil was considerably wet due to recent rains. For the RPT to occur, it is thought that the liquid must travel into the ground and insulate itself in pockets at it slowly warms up to (and above) the boiling point. The material can then undergo a spontaneous rapid transition to the vapor phase, creating the RPT eruption. Chlorine is

[b] G.A. Melhem, S. Saraf, H. Ozog, *"LNG Properties and Hazards: Understand Rapid Phase Transitions (RPT)"*, ioMosaic Corporation, Salem, New Hampshire, 2006.

a hydrophobic molecule and does not have a high affinity for water, and will therefore be more amenable to collecting in pockets than anhydrous ammonia in wet soil. Anhydrous ammonia, by contrast will likely simply dissolve in the water content of the soil rather than collecting in concentrated pockets.

6.1.4 Dense Gas Conclusions

Dense gas behavior was unambiguously observed and qualitatively characterized for the trials involving low wind conditions. For the low wind speeds observed (< ~1.5 m/s), it is evident that dense gas considerations dominate the initial behavior and movement of chlorine and anhydrous ammonia, especially when blocking or trapping terrain features are present (such as a depression basin). However, at higher wind speeds (> ~3.5 m/s), the wind clearly had an immediate and more prominent effect on how the material spread and behaved after the release. Additionally a previously unreported phenomenon was discovered during the chlorine trials. It was observed that rapid phase transitions (RPT) are common and frequent occurrences with rapid 1-ton and larger chlorine releases where the material impacts and can collect on the ground. These events were not noted for the anhydrous ammonia trials.

This report documents the observations only of the dense gas behavior from the Jack Rabbit trials. Several in-depth reviews and analyses of the vast amounts of collected data are planned through a separately-funded program by CSAC once all the data from the Jack Rabbit trials has been consolidated and made available. These studies will supplement and greatly expand upon the observations presented in this report, revealing quantitative results and findings that are of great value for efforts to model and understand the dense gas behavioral aspects of these materials.

7.0 Downwind Effects Assessment

This section provides documentation of the observed downwind behavior of anhydrous ammonia and chlorine during the trials. Although the data relevant to atmospheric transport and dispersion studies (downwind effects) has not yet been analyzed, the observations from the trials have been captured and documented in this report. This report is not intended to be an exhaustive review or analysis of the collected datasets. Comprehensive studies and analyses will be conducted through additional follow-on tasks which are planned to begin in FY 2011 when all datasets have been collected and made available.

7.1 Trial Observations

The gases used in the trials, anhydrous ammonia and chlorine, initially exhibit dense gas behavior initially upon release from containment. However, after a certain time the material became neutrally buoyant due to a combination of the gas warming, additional air entrainment, diffusion into the surrounding atmosphere. Once in this state, the gas was easily carried downwind.

It is important to note that the prioritized objective of the Jack Rabbit trials was to investigate the source component of the release, and the near-field dense gas characteristics and behavior of chlorine and anhydrous ammonia. However, in order to more fully take advantage of the rare field releases, additional experimentation was included to investigate the atmospheric transport and dispersion of these chemicals downwind.

Detection instrumentation was deployed out to a range of 500 meters, with some point detection MiniRAE instruments recording data at multiple heights, including 1-m, 3-m, and 6-m. This vertical profile is important in that it allows for the possibility of performing calculations to attempt to determine the flux of gas though a y-z plane – an important metric for atmospheric transport and dispersion studies. Additionally, data were recorded from several stand-off instruments and video stations to capture the behavior of the cloud as it dispersed downwind.

The wind roses presented in Figures 12-21 illustrate the wind conditions from 30 minutes prior to the dissemination until 60 minutes after the release. Wind roses provide a graphical representation of the frequency at which a wind direction occurs along with the wind speed within a given direction. It is important to note that the direction specified is the direction that the wind is *coming from*, not going toward.

The data used for these figures were obtained from 10-second averages from the 16 PWIDS stations deployed around the Jack Rabbit test grid. Photographs in those figures were captured 45 seconds into the dissemination. All photographs were taken from the South tower looking toward the North. The information presented in Figures 12-21 provides an initial look at the downwind movement of the chemical clouds 45 seconds after release, when the dense gas cloud is just beginning to exhibit some neutrally buoyant characteristics.

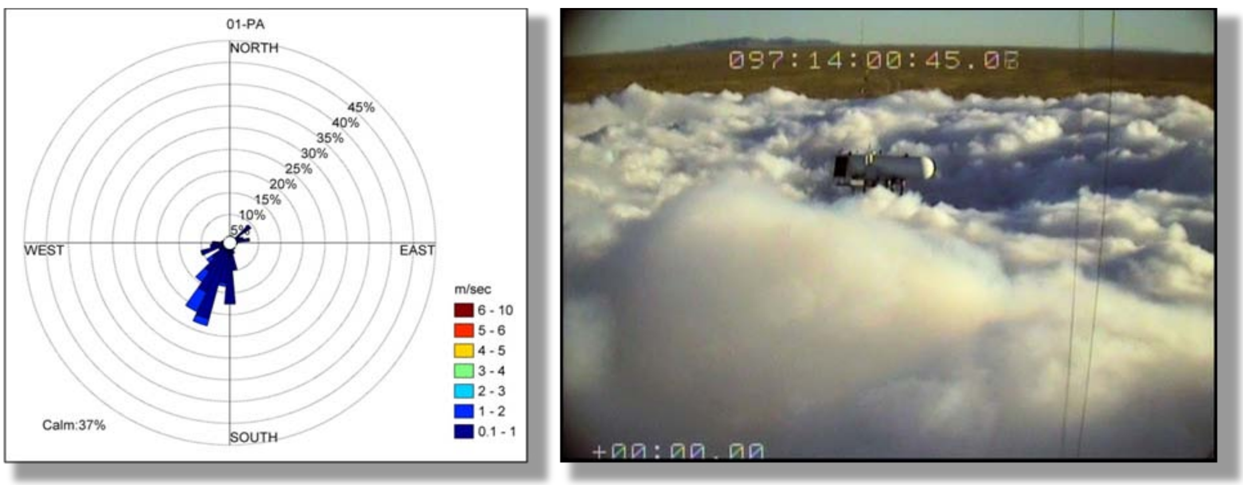

Figure 12. Trial 01-PA Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

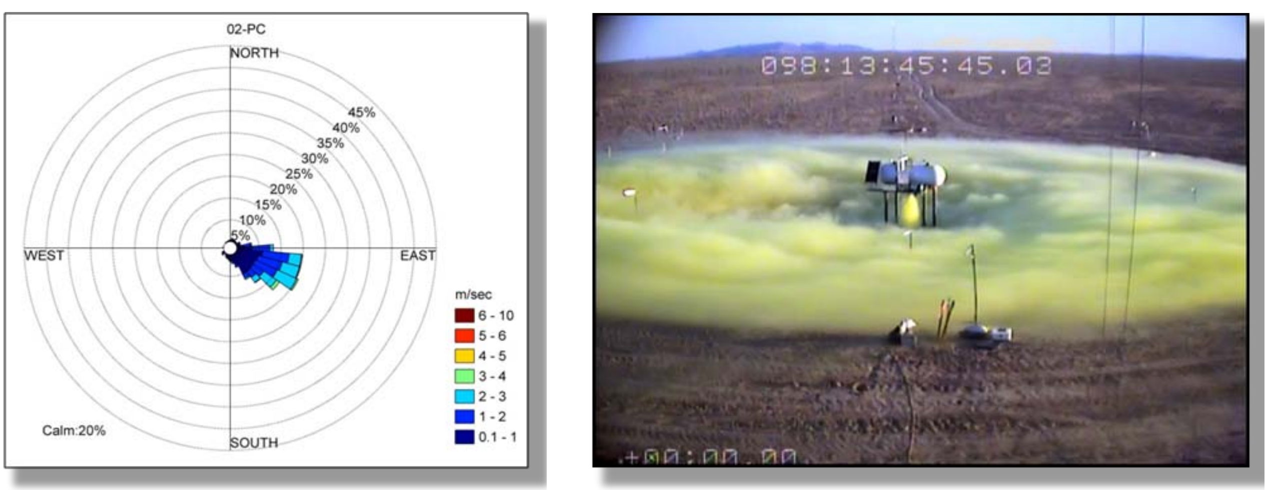

Figure 13. Trial 02-PC Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

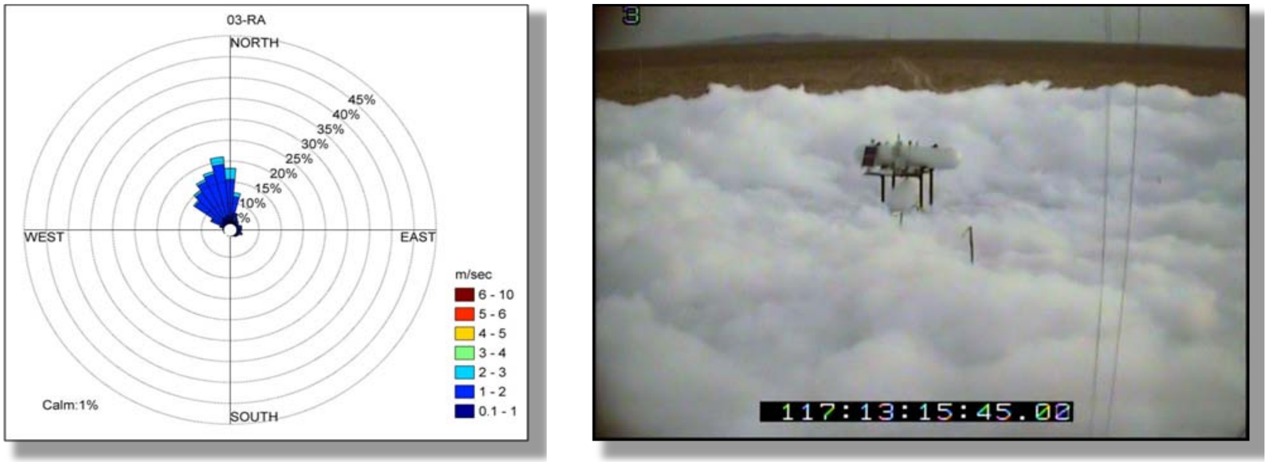

Figure 14. Trial 03-RA Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

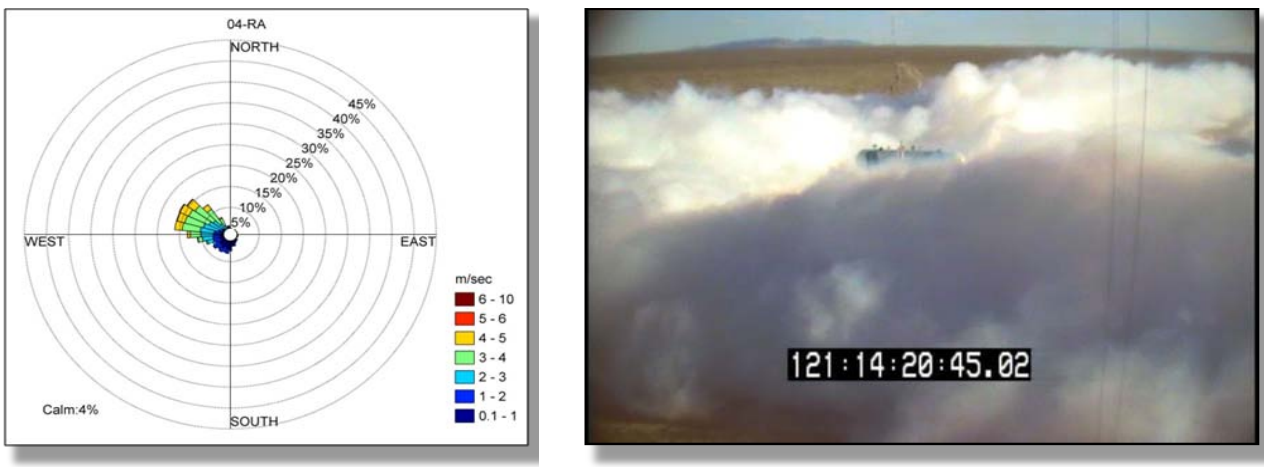

Figure 15. Trial 04-RA Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

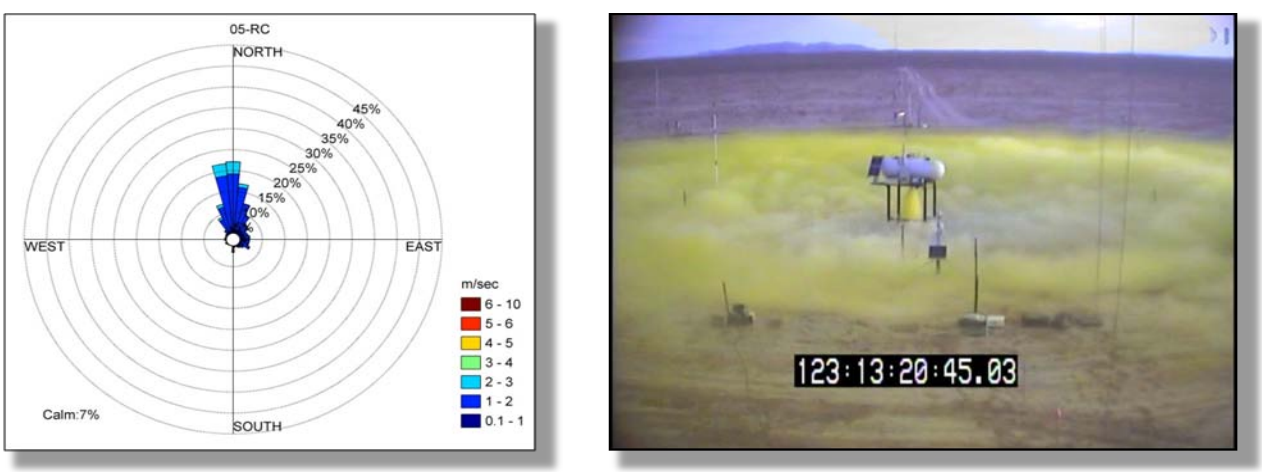

Figure 16. Trial 05-RC Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

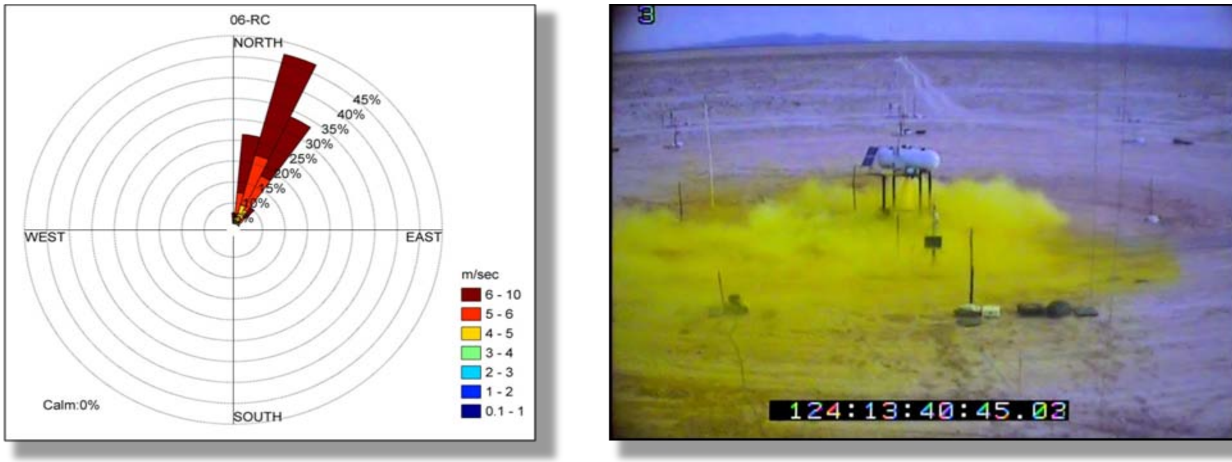

Figure 17. Trial 06-RC Wind Rose Graph and South View at 45 Seconds After Dissemination

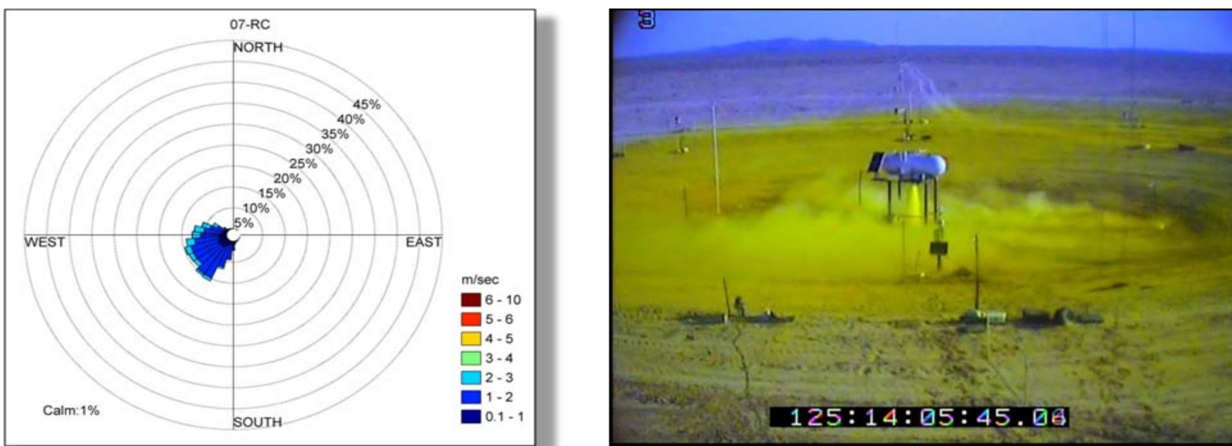

Figure 18. Trial 07-RC Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

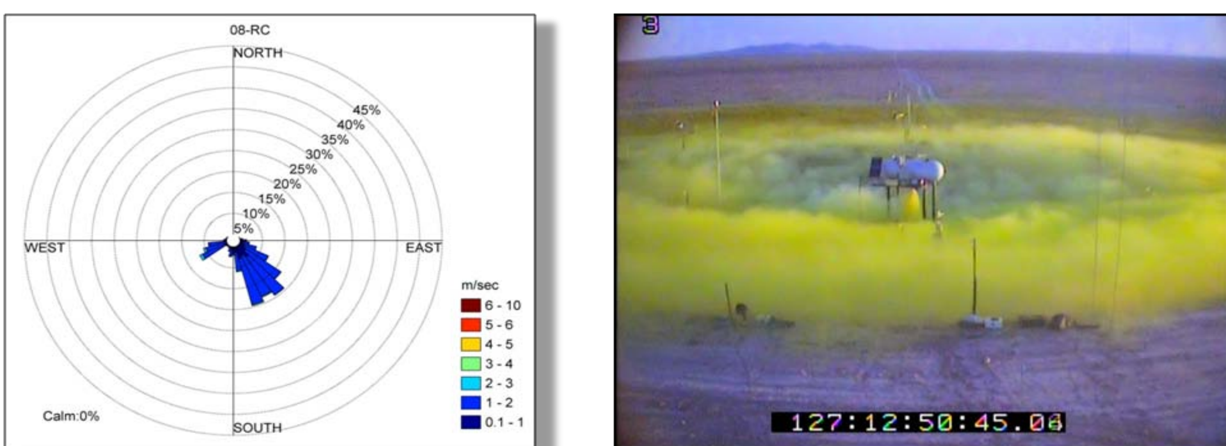

Figure 19. Trial 08-RC Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

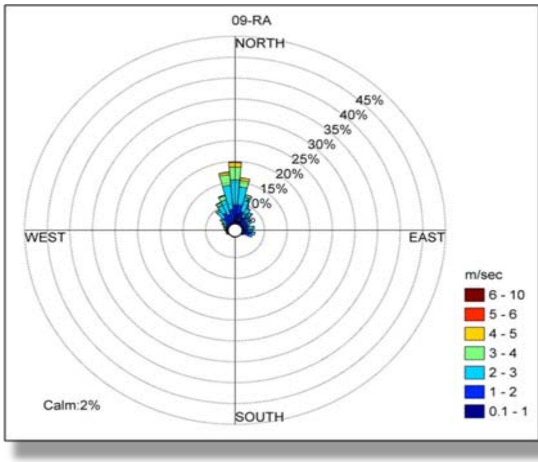

Figure 20. Trial 09-RA Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

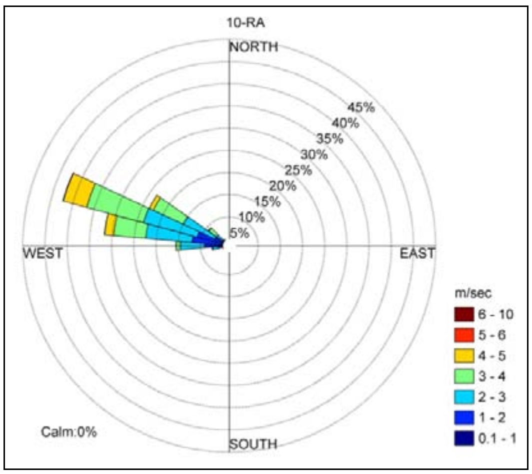

Figure 21. Trial 10-RA Wind Rose Graph and South Tower View at 45 Seconds After Dissemination

7.2 Hazard Prediction and Assessment Capability (HPAC) Modeling

Prior to, and during disseminations, the WDTC Meteorology Division conducted multiple model runs using the HPAC software developed through the Defense Threat Reduction Agency (DTRA). For these model runs, contour plots were created to display threshold concentration levels. For the increased safety of all Jack Rabbit test participants, the concentration levels used during the test project were set at lower thresholds then what is prescribed by the National Institute for Occupational Safety and Health (NIOSH). Figures 22 through 31 illustrate the HPAC model runs based on the meteorological conditions at the time of each trial. These illustrations are predictive results and are not based on chemical sensor detection.

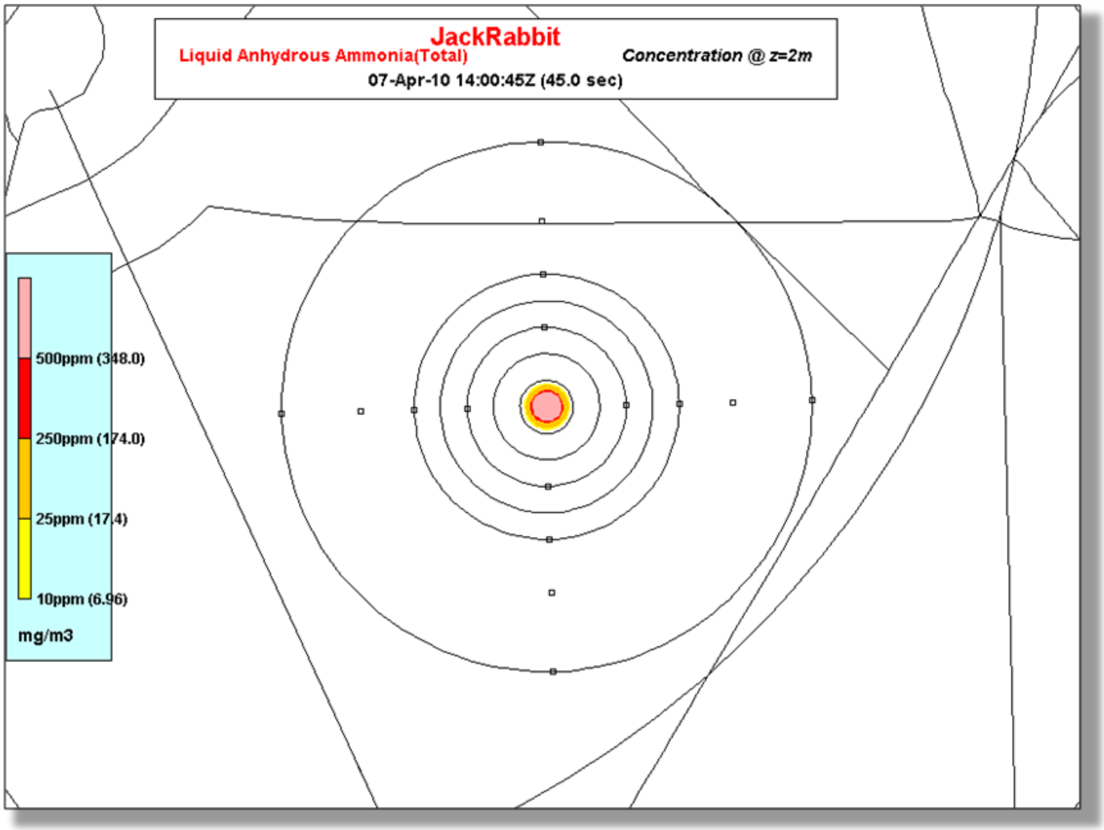

Figure 22a. Trial 01-PA HPAC Modeling at 45 Seconds After Dissemination

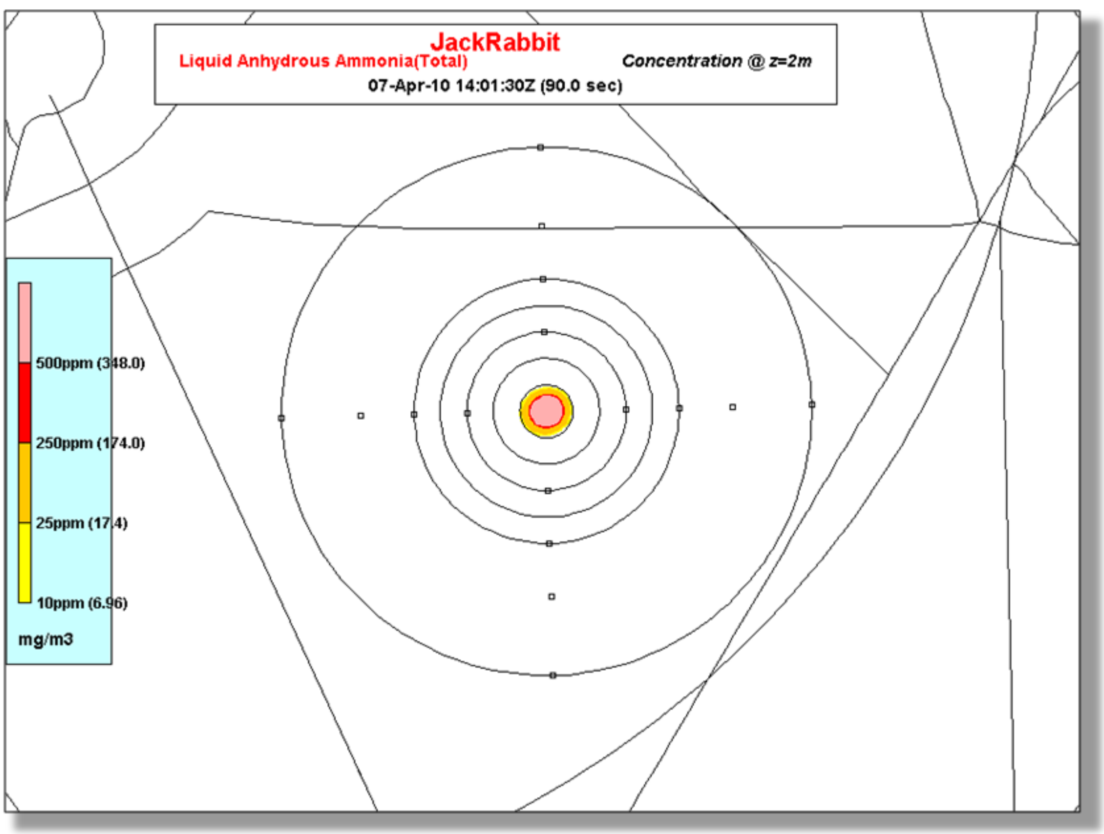

Figure 22b. Trial 01-PA HPAC Modeling at 90 Seconds After Dissemination

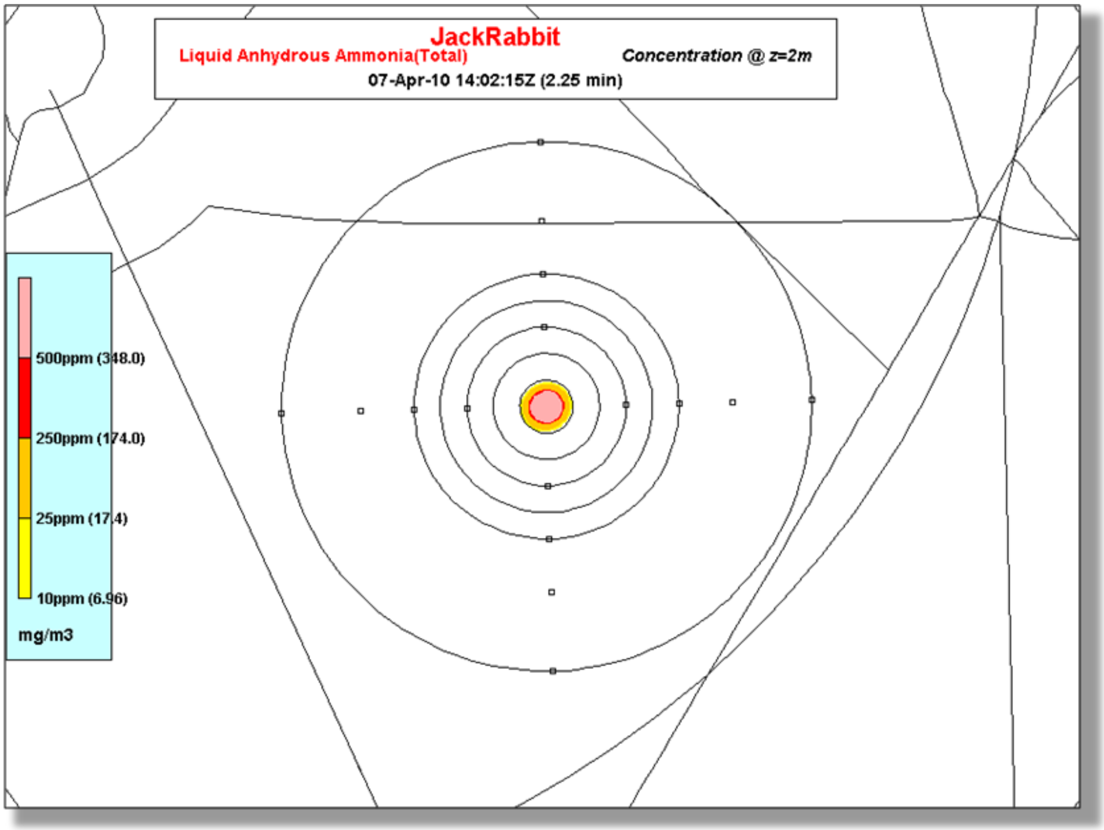

Figure 22c. Trial 01-PA HPAC Modeling at 135 Seconds After Dissemination

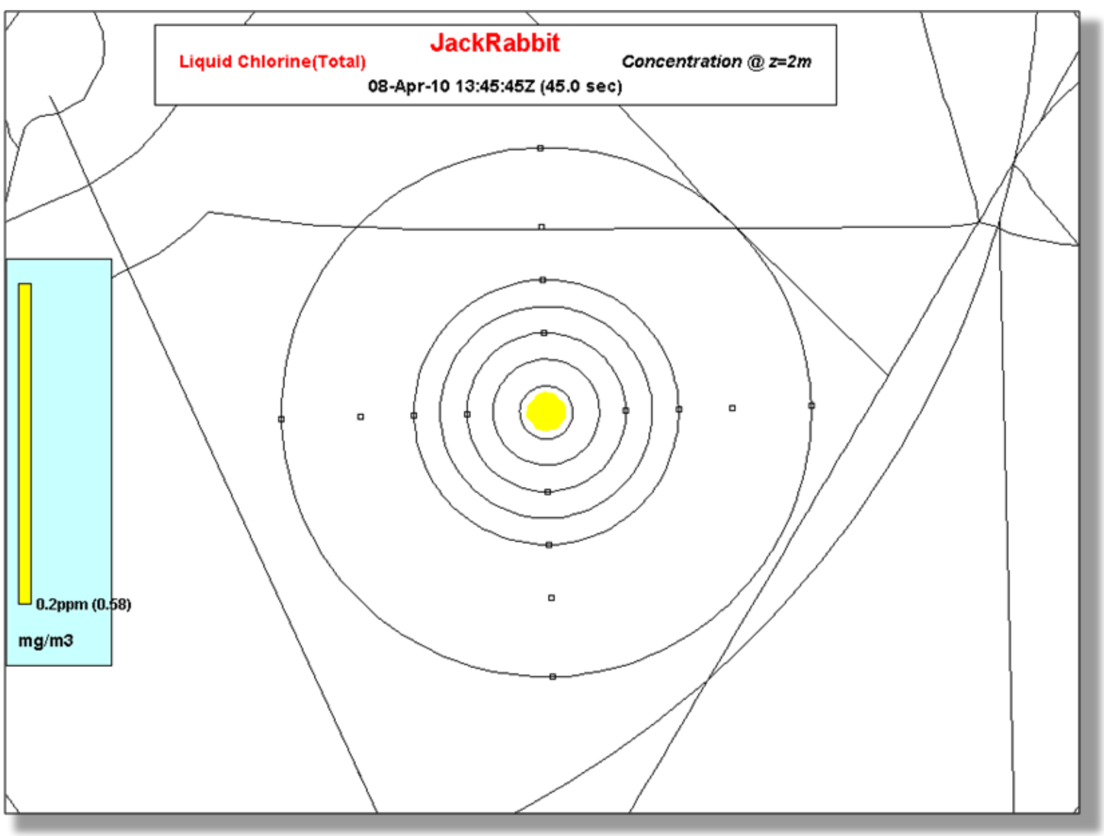

Figure 23a. Trial 02-PC HPAC Modeling at 45 Seconds After Dissemination

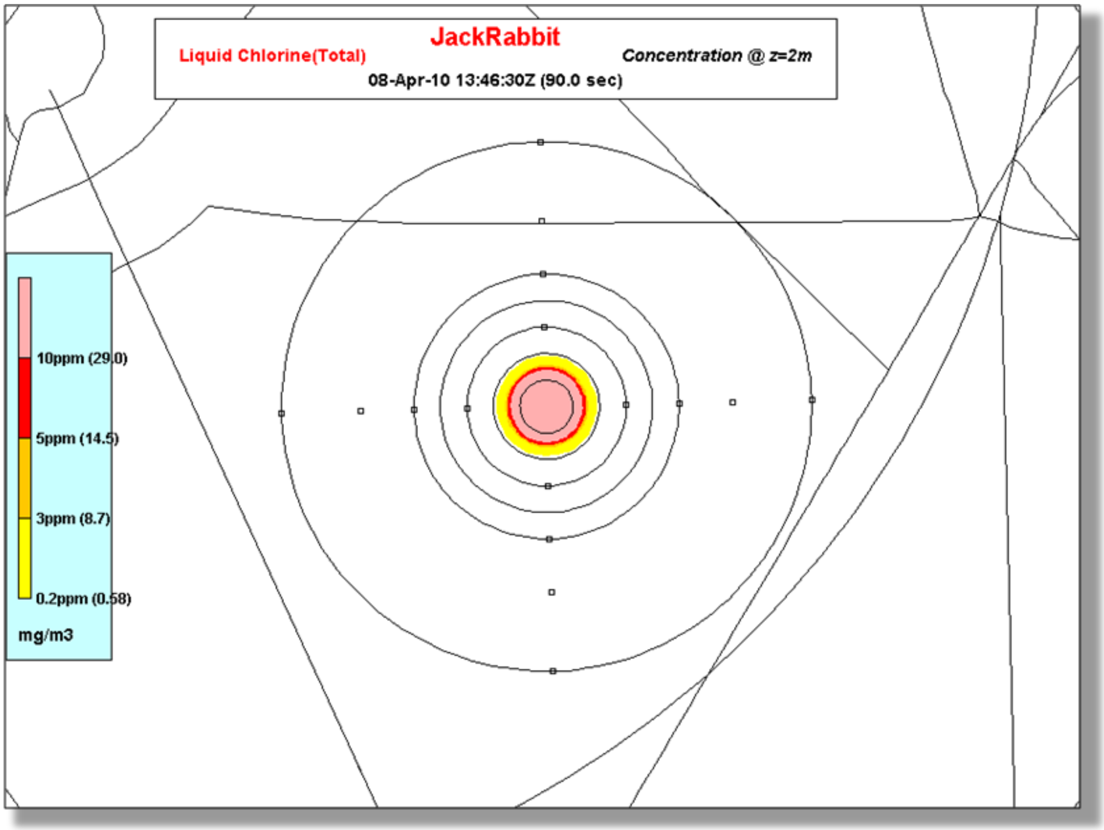

Figure 23b. Trial 02-PC HPAC Modeling at 90 Seconds After Dissemination

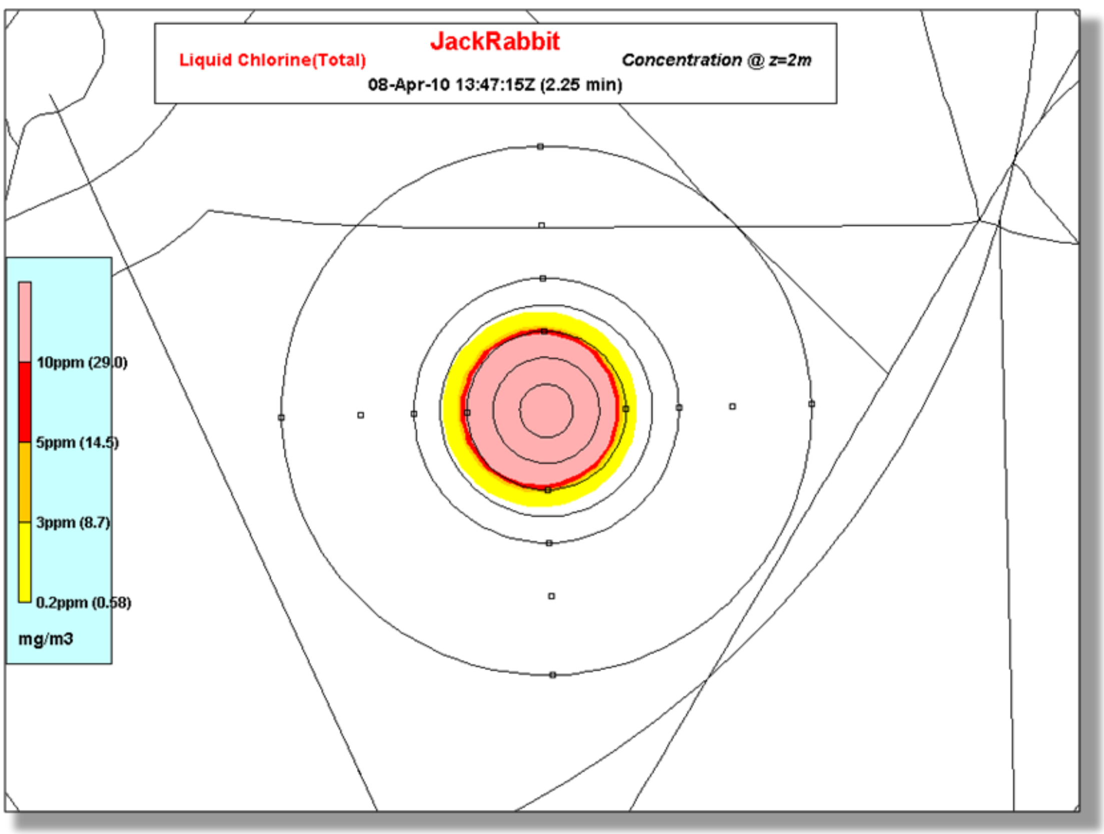

Figure 23c. Trial 02-PC HPAC Modeling at 135 Seconds After Dissemination

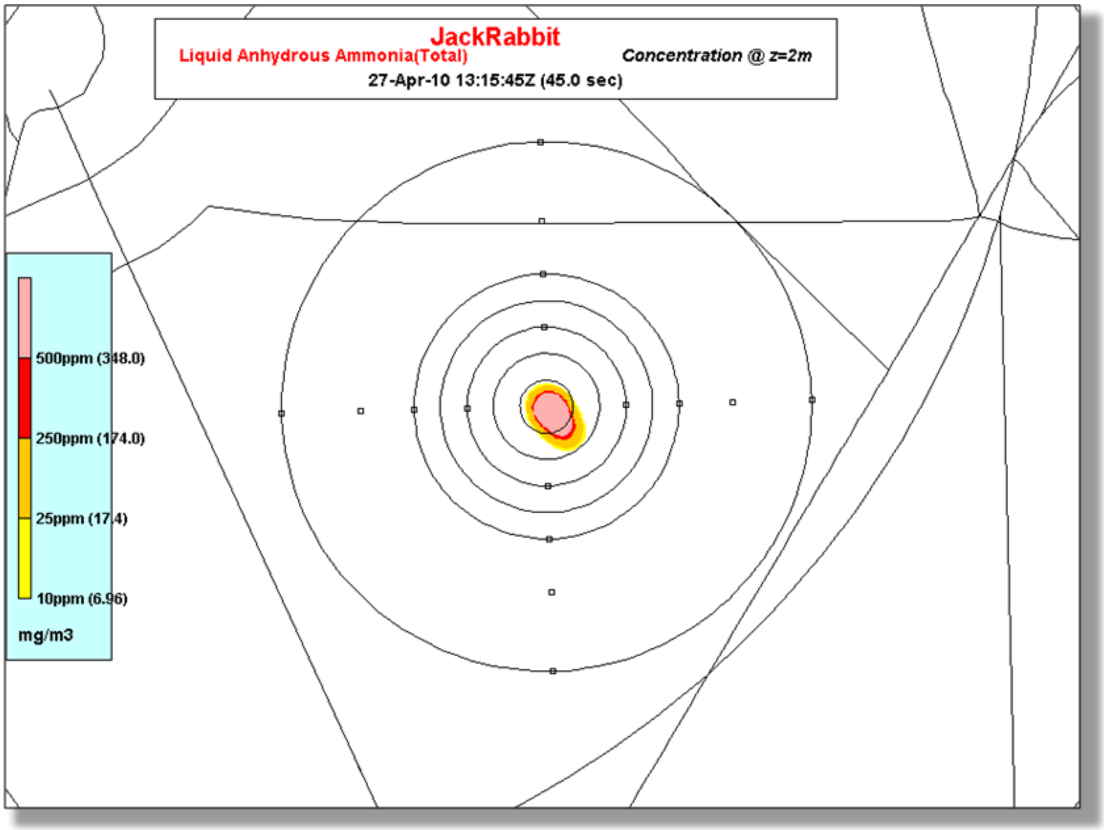

Figure 24a. Trial 03-RA HPAC Modeling at 45 Seconds After Dissemination

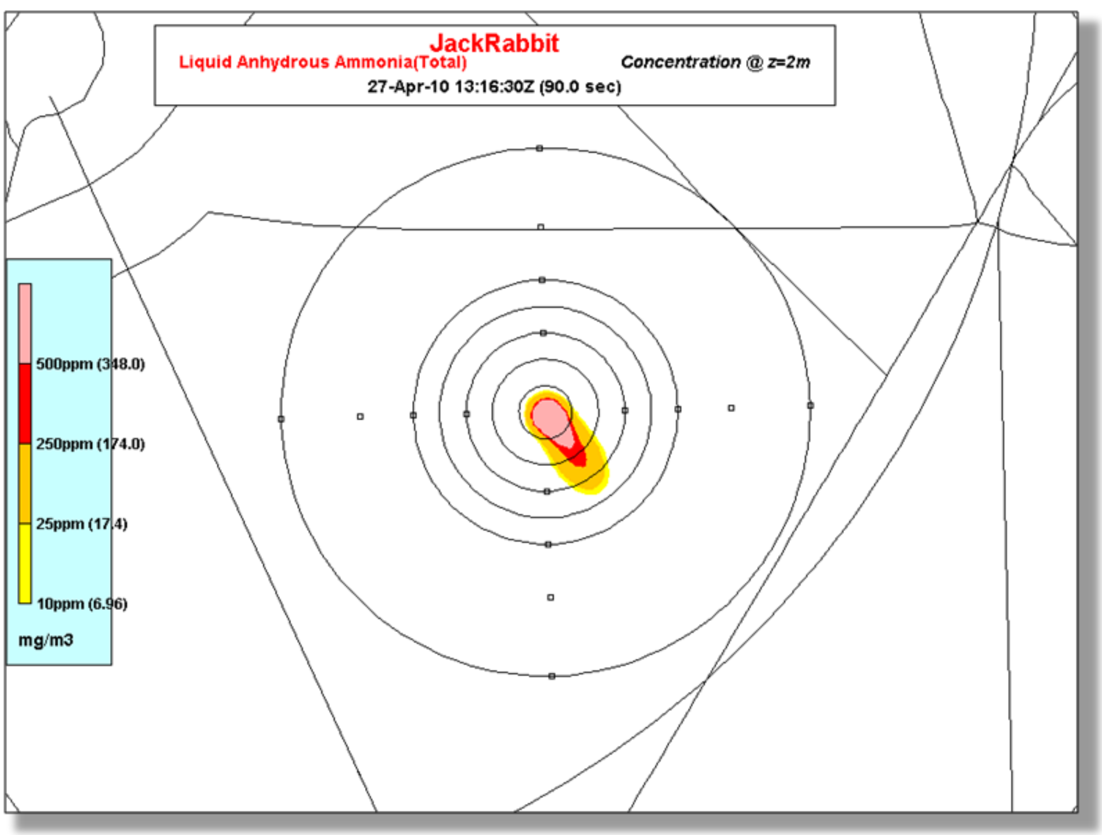

Figure 24b. Trial 03-RA HPAC Modeling at 90 Seconds After Dissemination

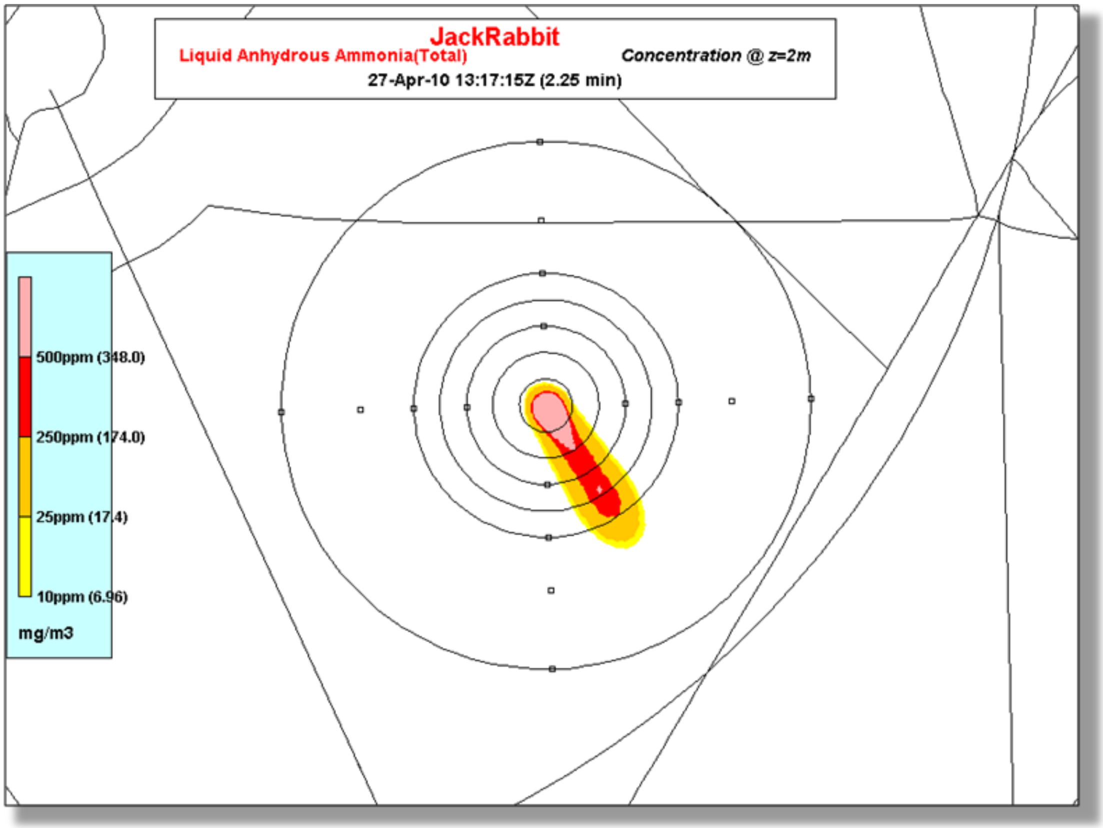

Figure 24c. Trial 03-RA HPAC Modeling at 135 Seconds After Dissemination

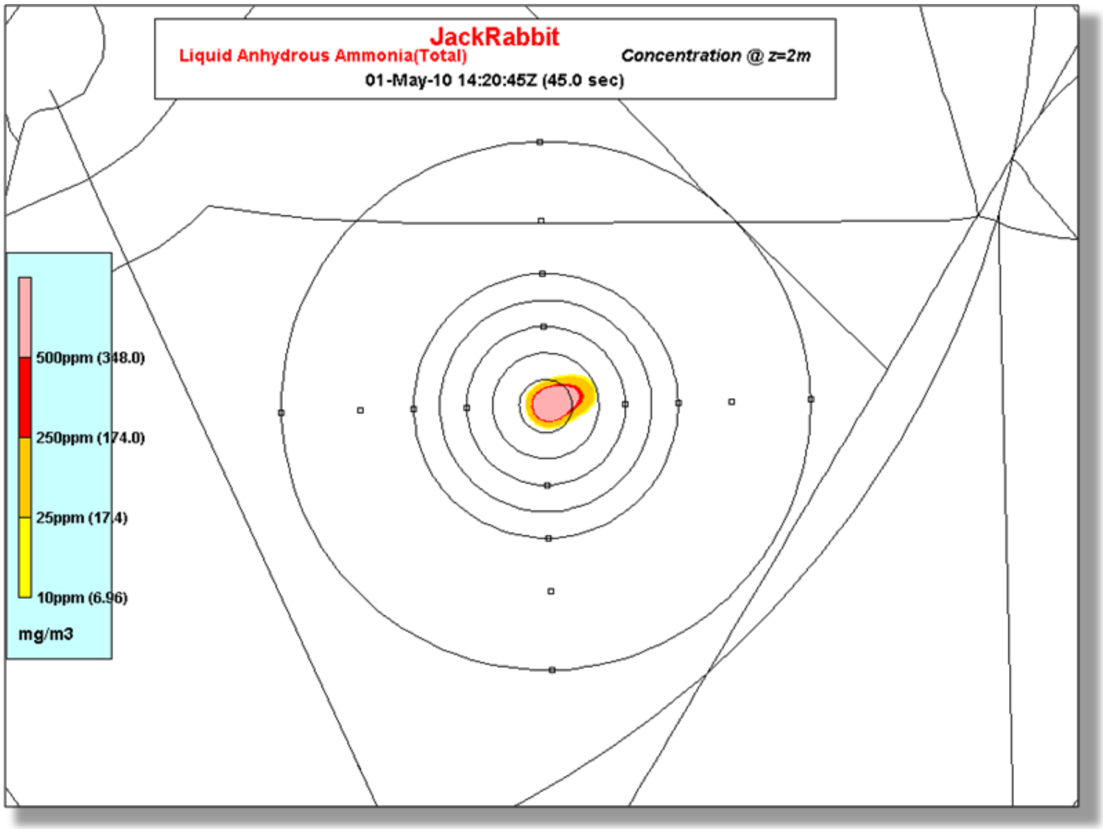

Figure 25a. Trial 04-RA HPAC Modeling at 45 Seconds After Dissemination

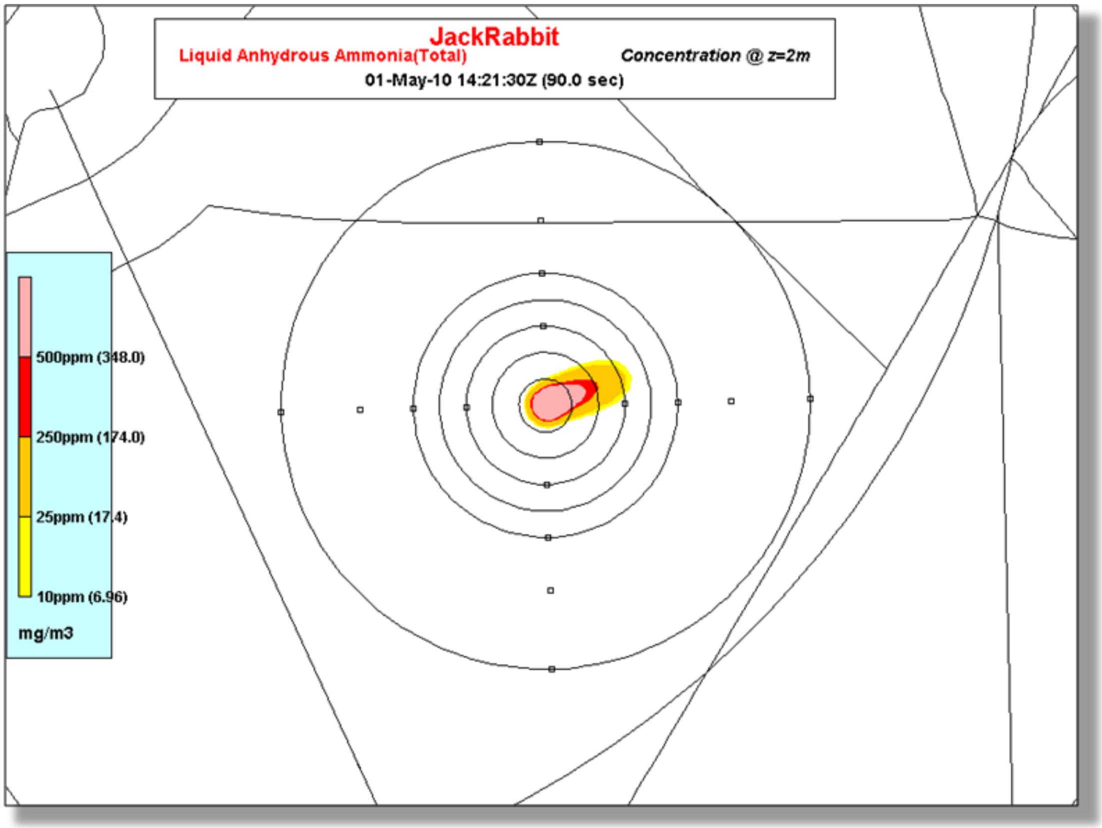

Figure 25b. Trial 04-RA HPAC Modeling at 90 Seconds After Dissemination

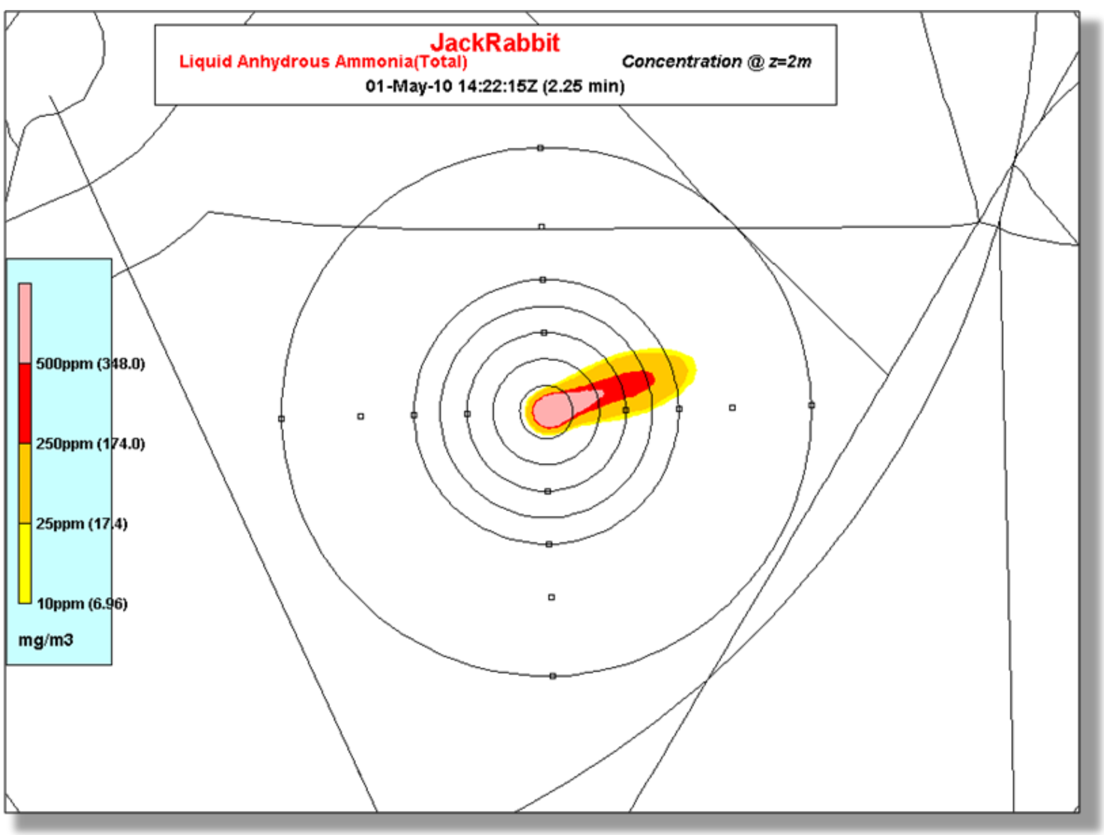

Figure 25c. Trial 04-RA HPAC Modeling at 135 Seconds After Dissemination

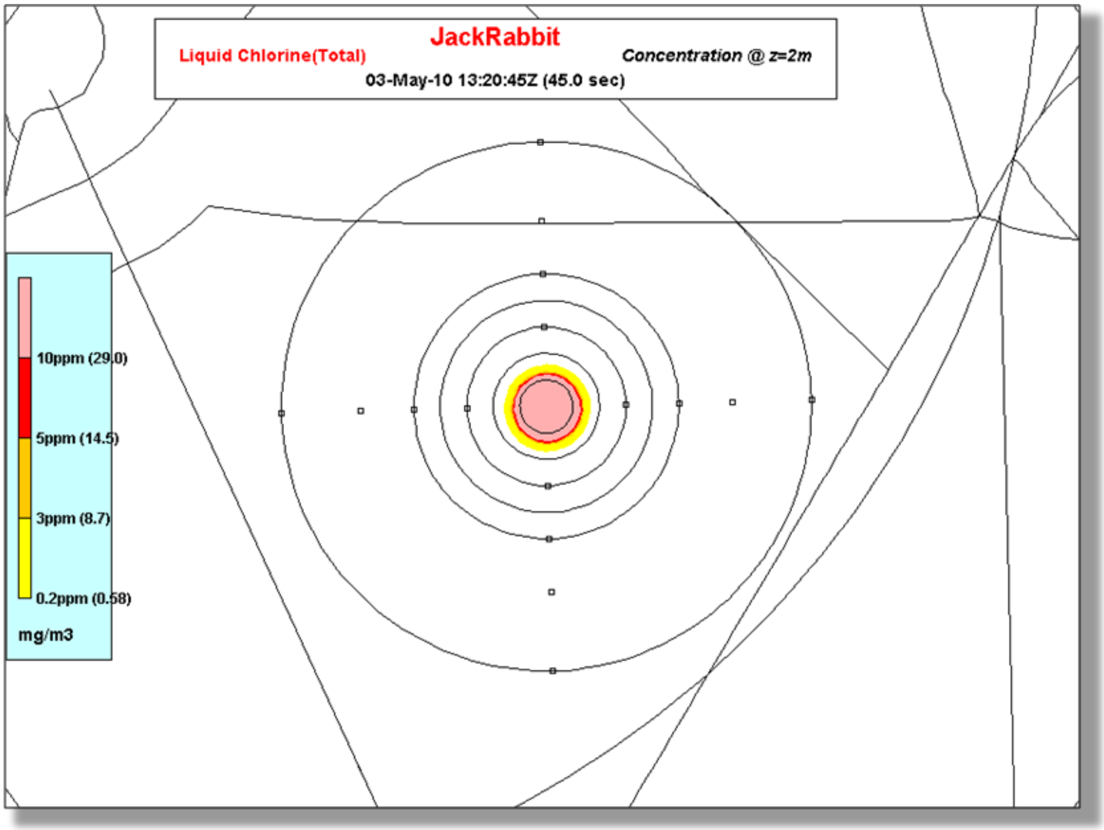

Figure 26a. Trial 05-RC HPAC Modeling at 45 Seconds After Dissemination

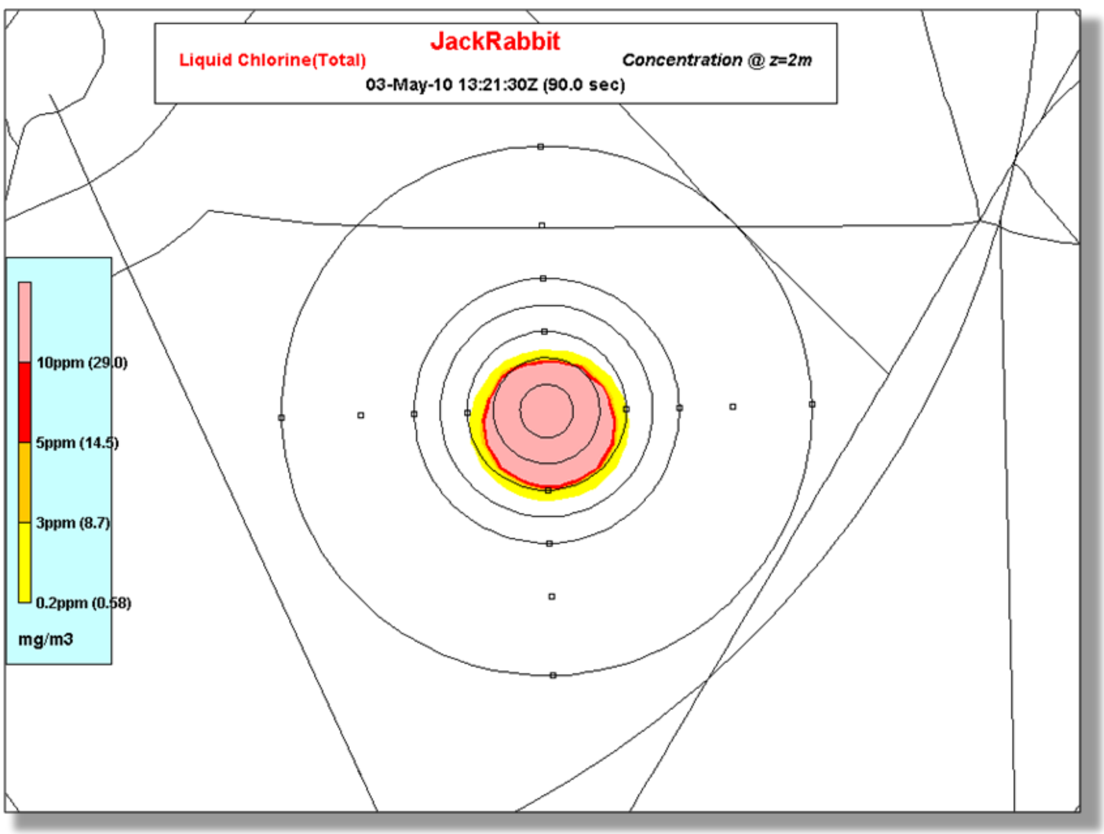

Figure 26b. Trial 05-RC HPAC Modeling at 90 Seconds After Dissemination

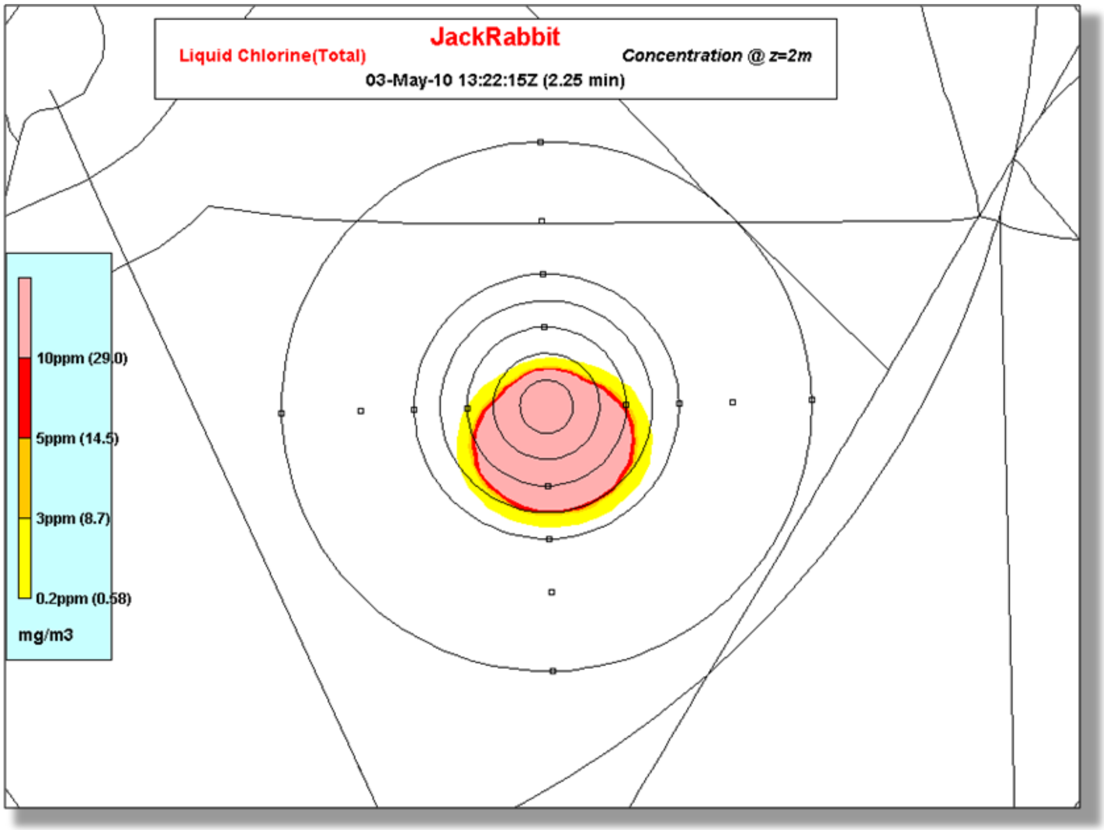

Figure 26c. Trial 05-RC HPAC Modeling at 135 Seconds After Dissemination

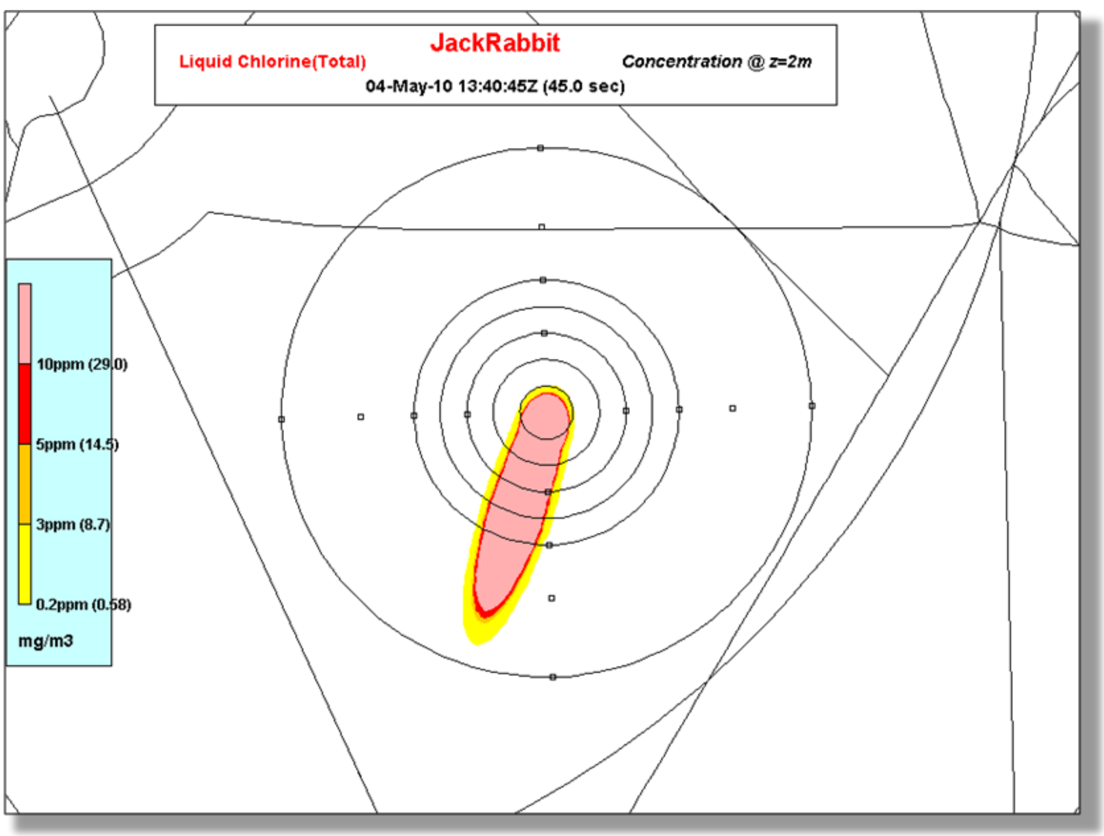

Figure 27a. Trial 06-RC HPAC Modeling at 45 Seconds After Dissemination

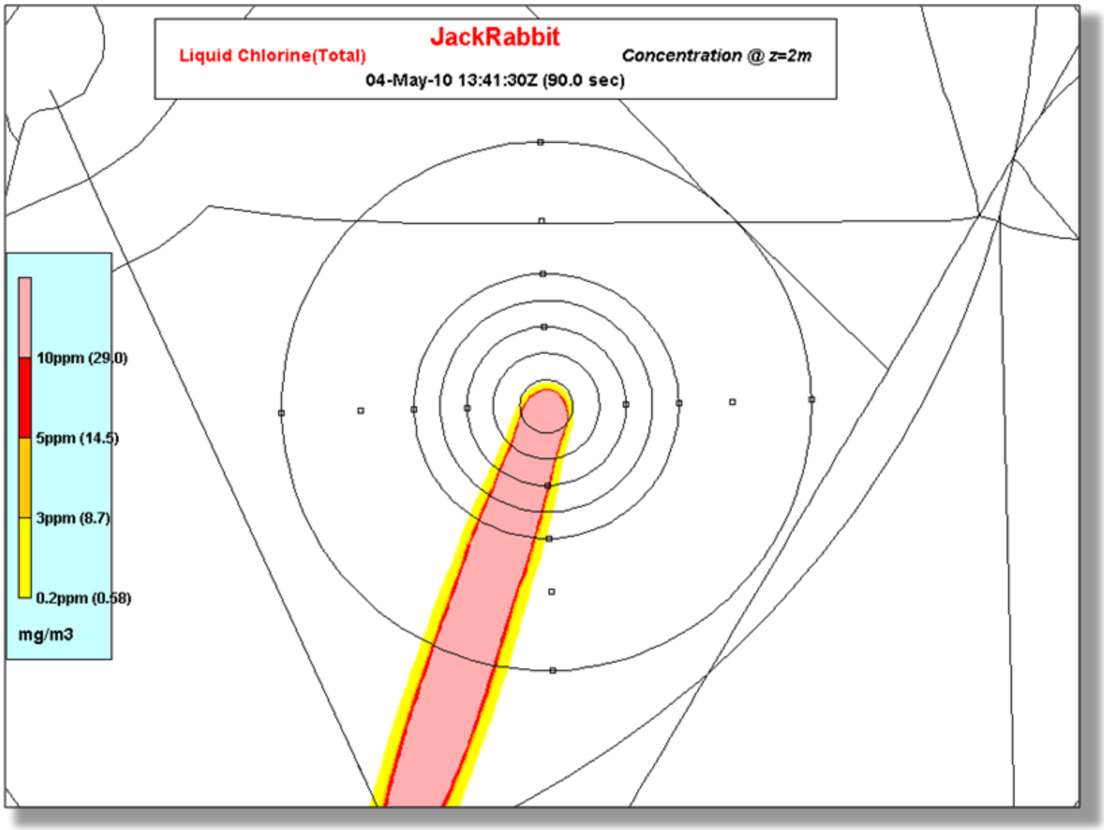

Figure 27b. Trial 06-RC HPAC Modeling at 90 Seconds After Dissemination

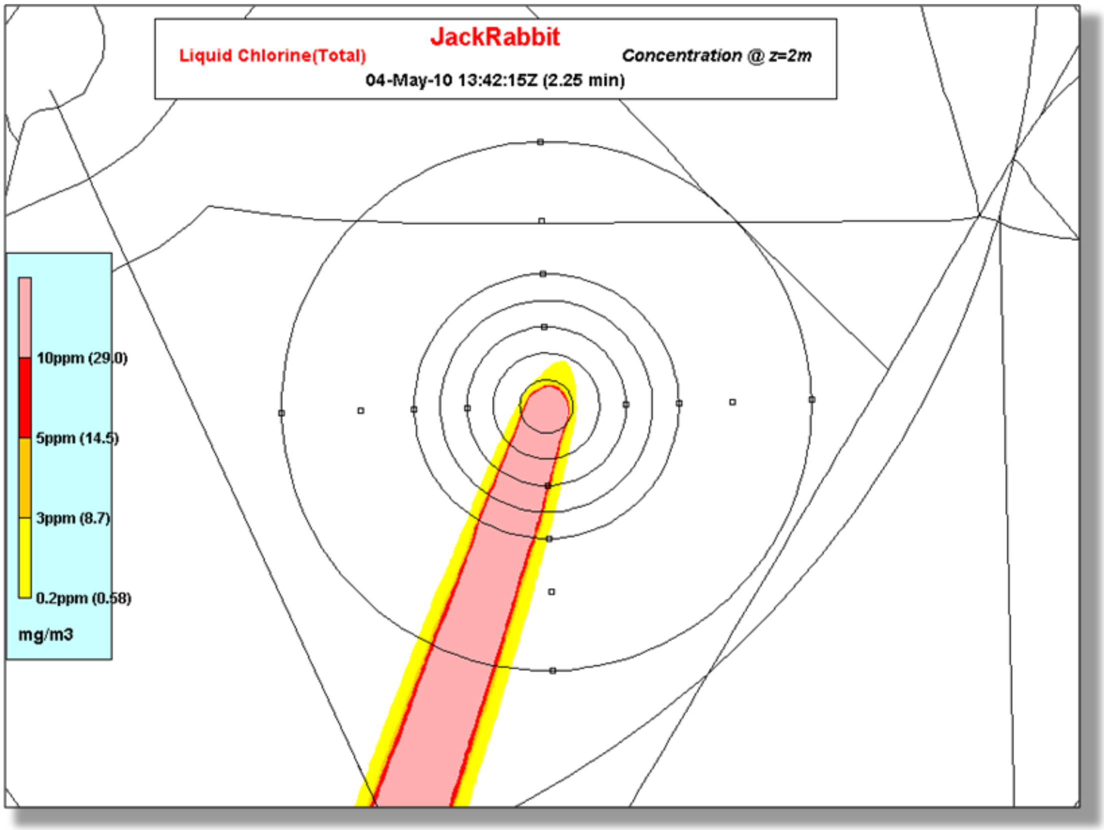

Figure 27c. Trial 06-RC HPAC Modeling at 135 Seconds After Dissemination

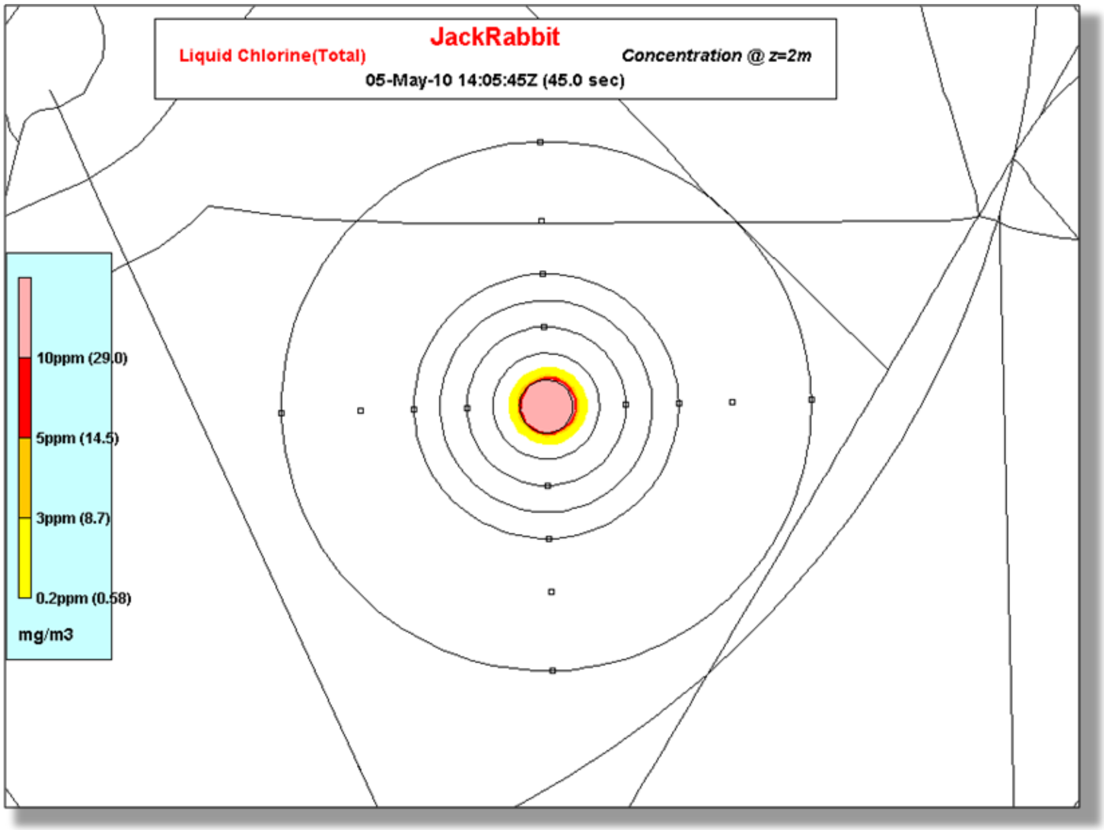

Figure 28a. Trial 07-RC HPAC Modeling at 45 Seconds After Dissemination

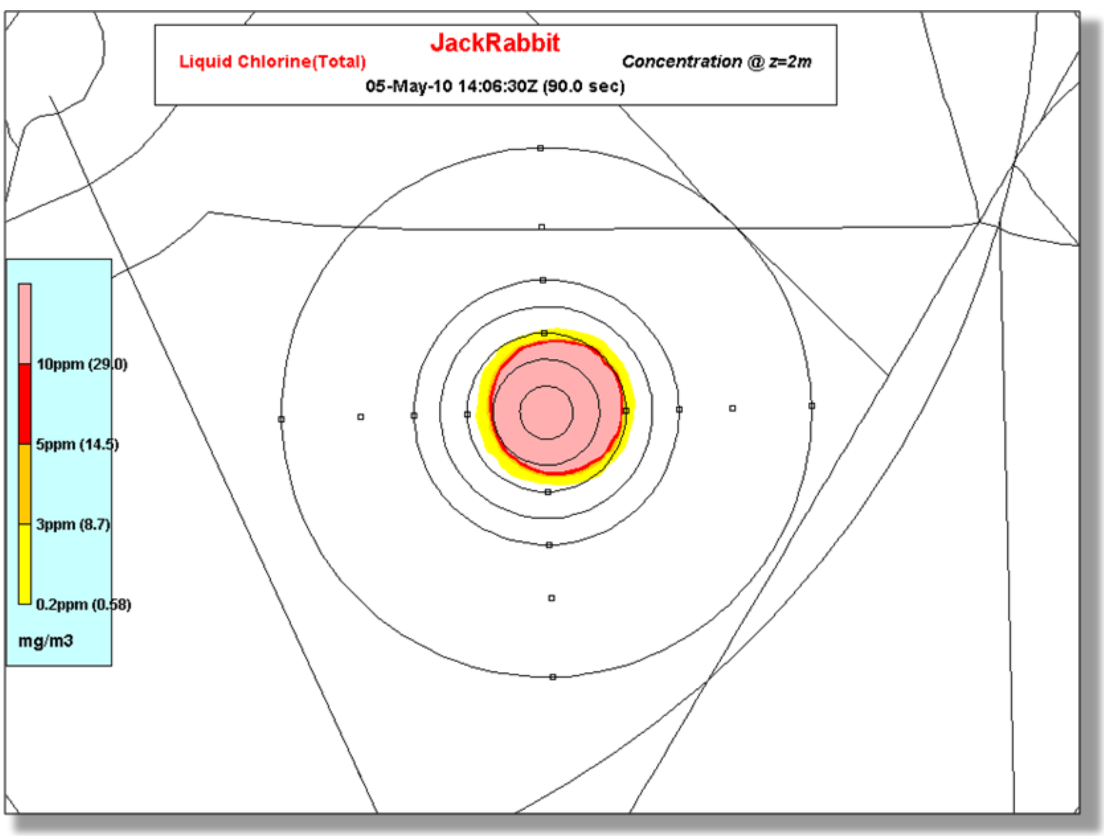

Figure 28b. Trial 07-RC HPAC Modeling at 90 Seconds After Dissemination

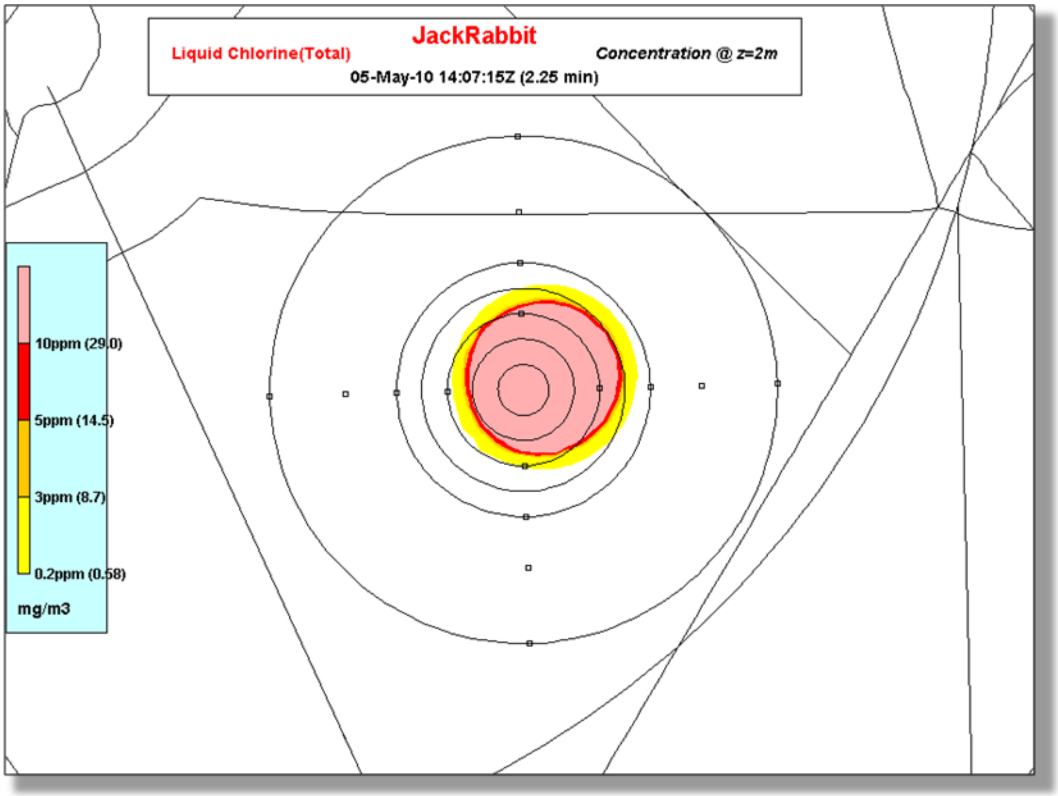

Figure 28c. Trial 07-RC HPAC Modeling at 135 Seconds After Dissemination

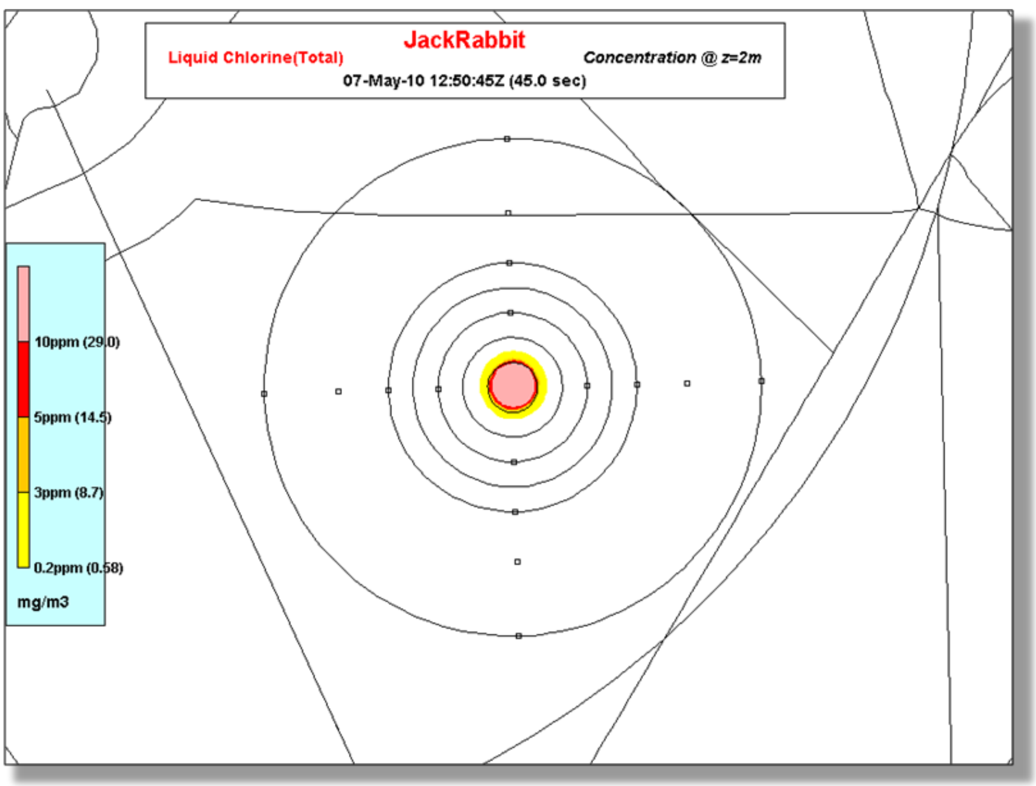

Figure 29a. Trial 08-RC HPAC Modeling at 45 Seconds After Dissemination

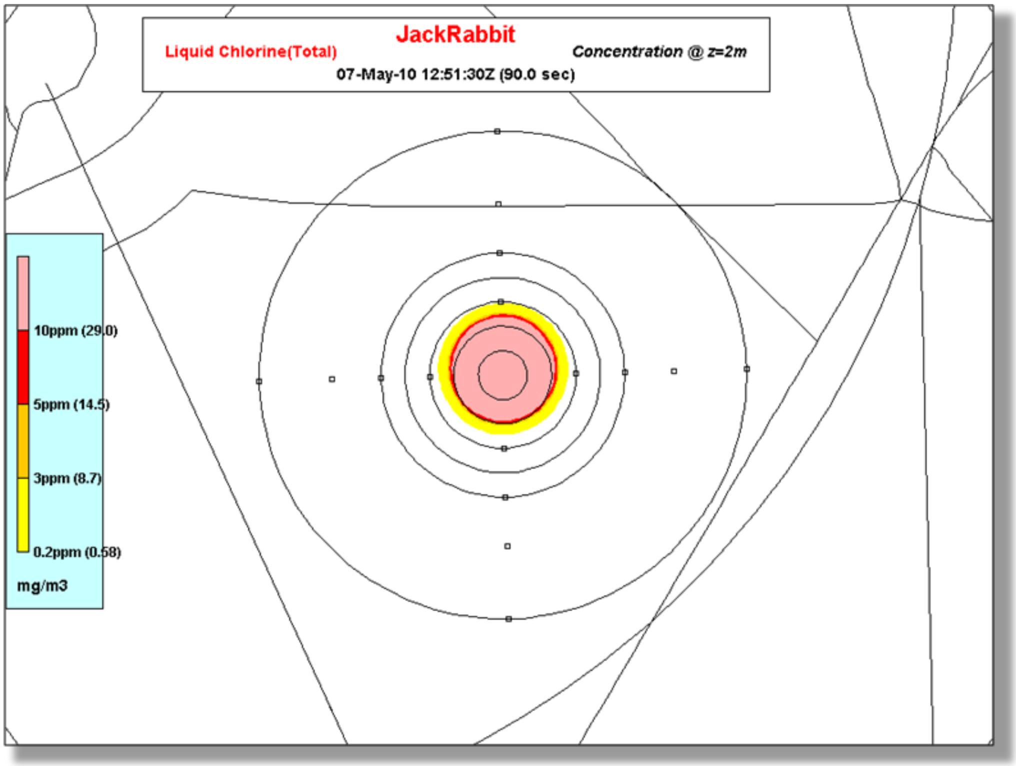

Figure 29b. Trial 08-RC HPAC Modeling at 90 Seconds After Dissemination

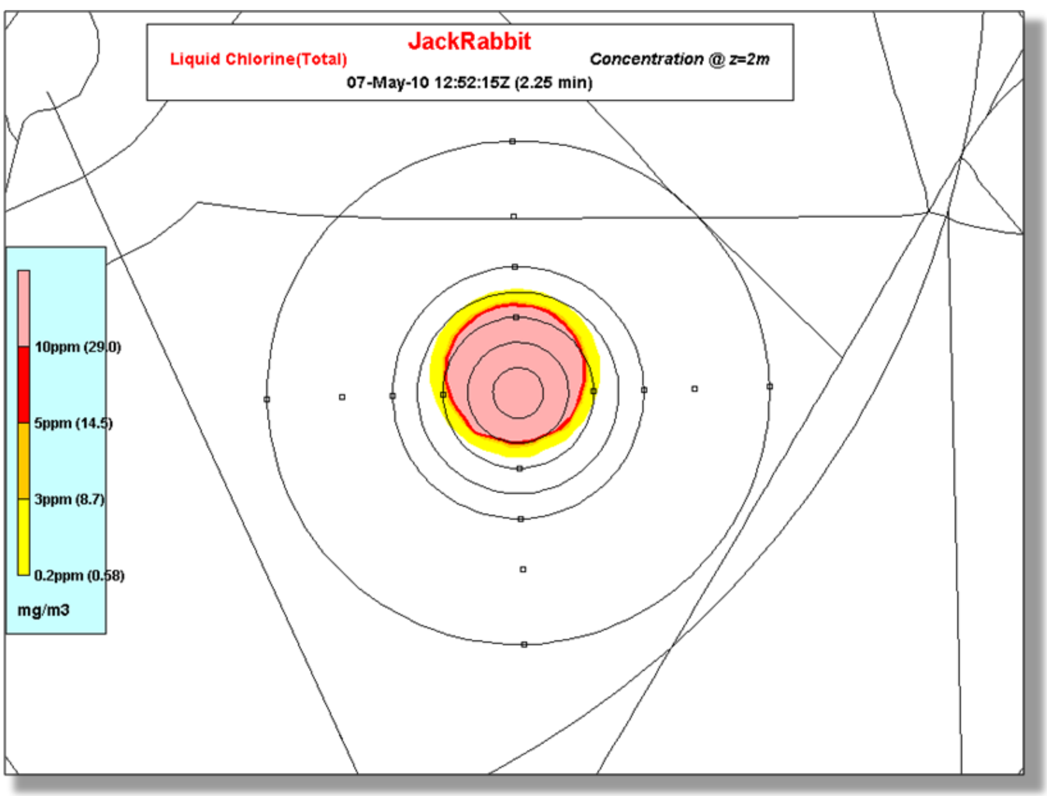

Figure 29c. Trial 08-RC HPAC Modeling at 135 Seconds After Dissemination

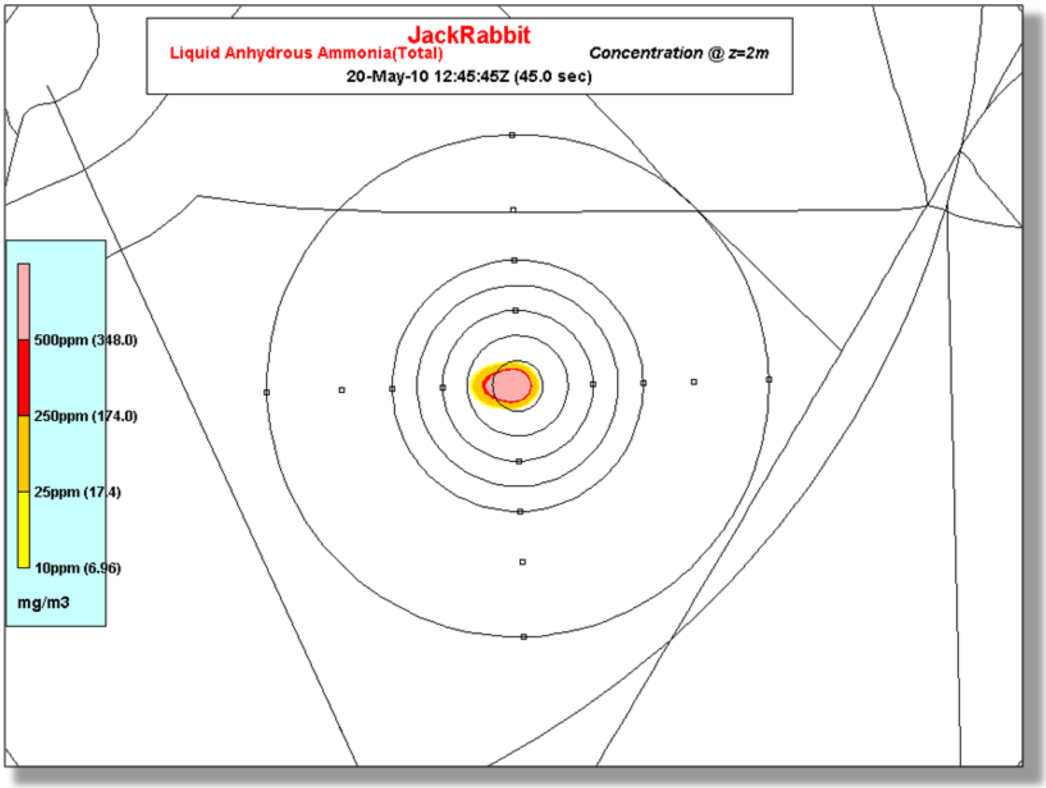

Figure 30a. Trial 09-RA HPAC Modeling at 45 Seconds After Dissemination

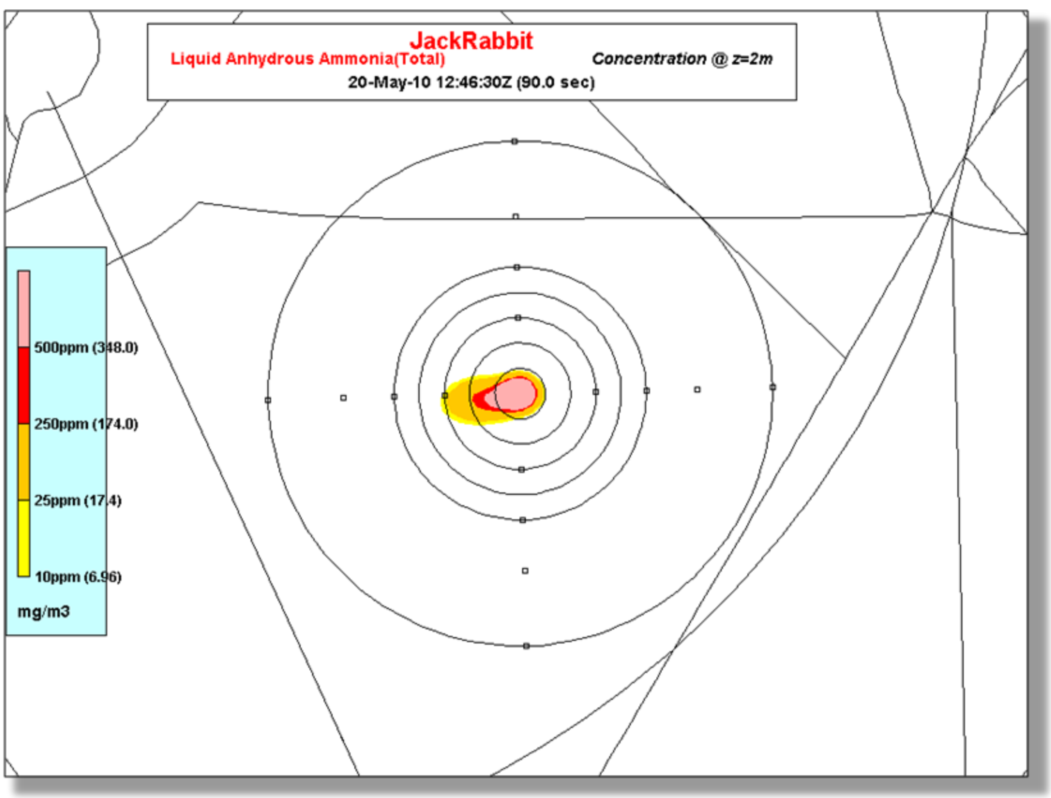

Figure 30b. Trial 09-RA HPAC Modeling at 90 Seconds After Dissemination

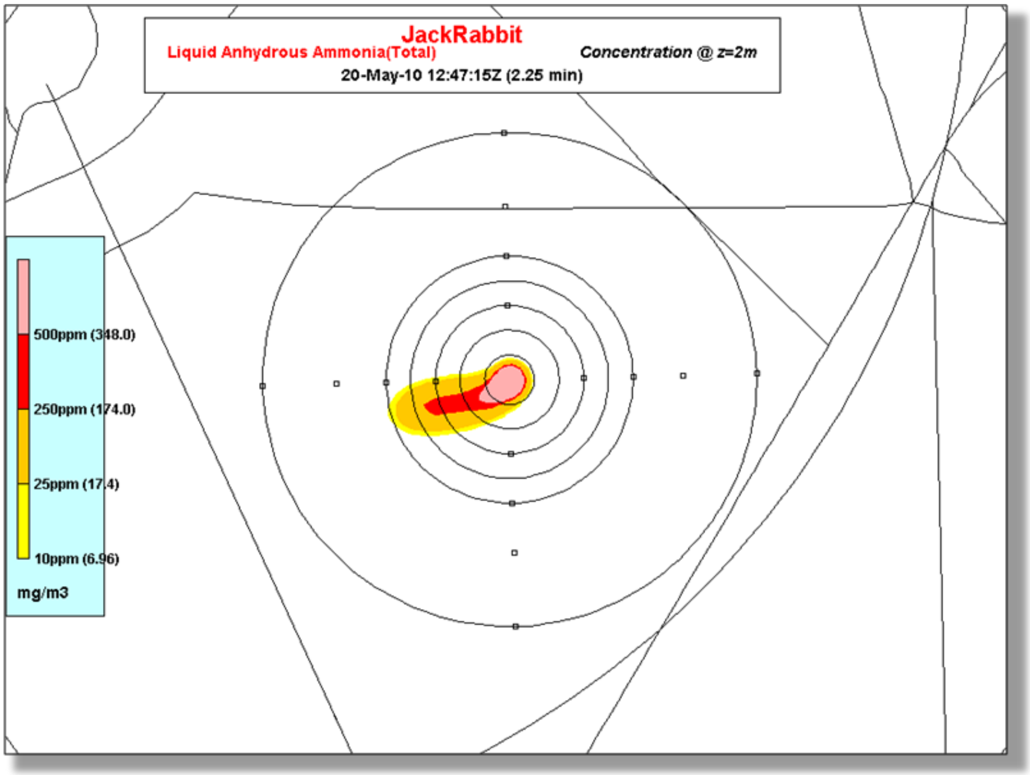

Figure 30c. Trial 09-RA HPAC Modeling at 135 Seconds After Dissemination

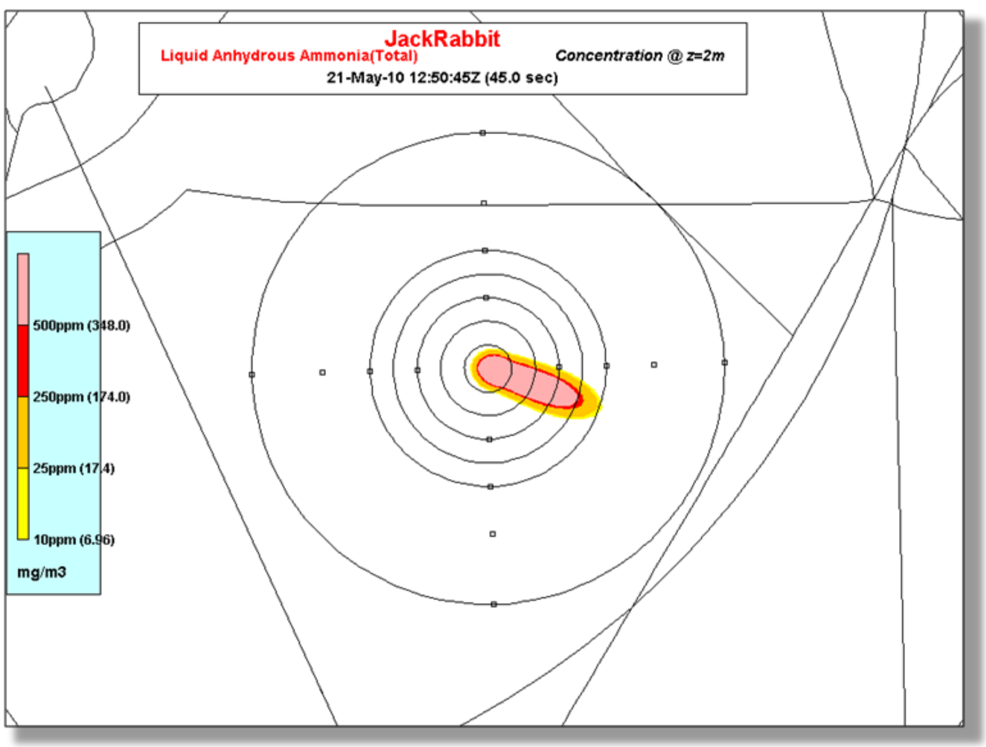

Figure 31a. Trial 10-RA HPAC Modeling at 45 Seconds After Dissemination

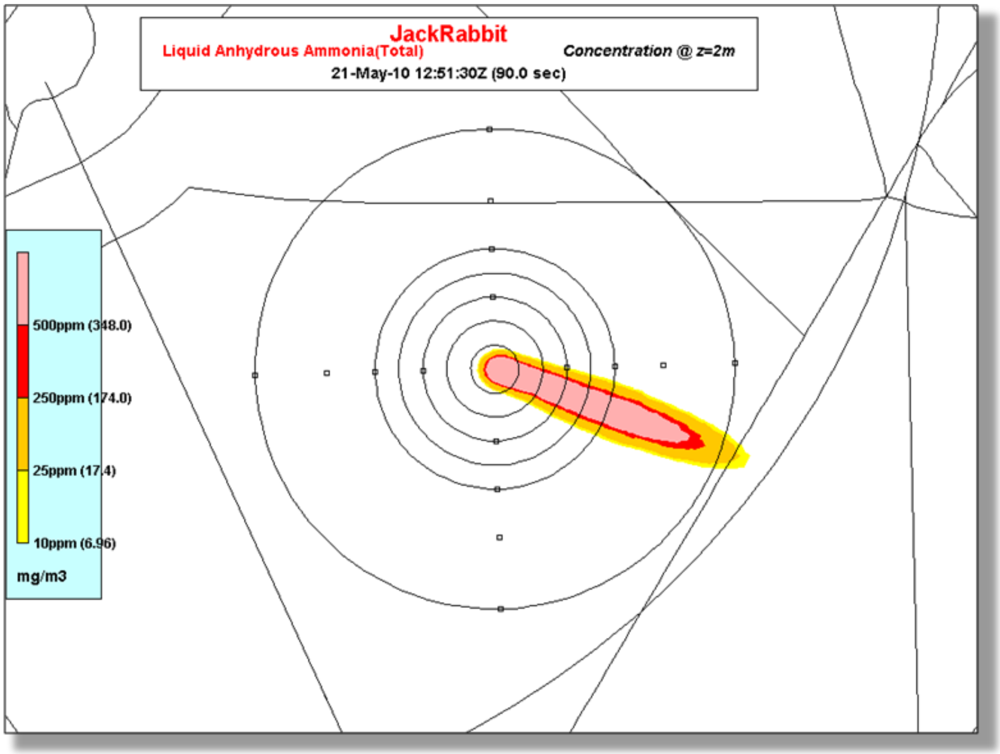

Figure 31b. Trial 10-RA HPAC Modeling at 90 Seconds After Dissemination

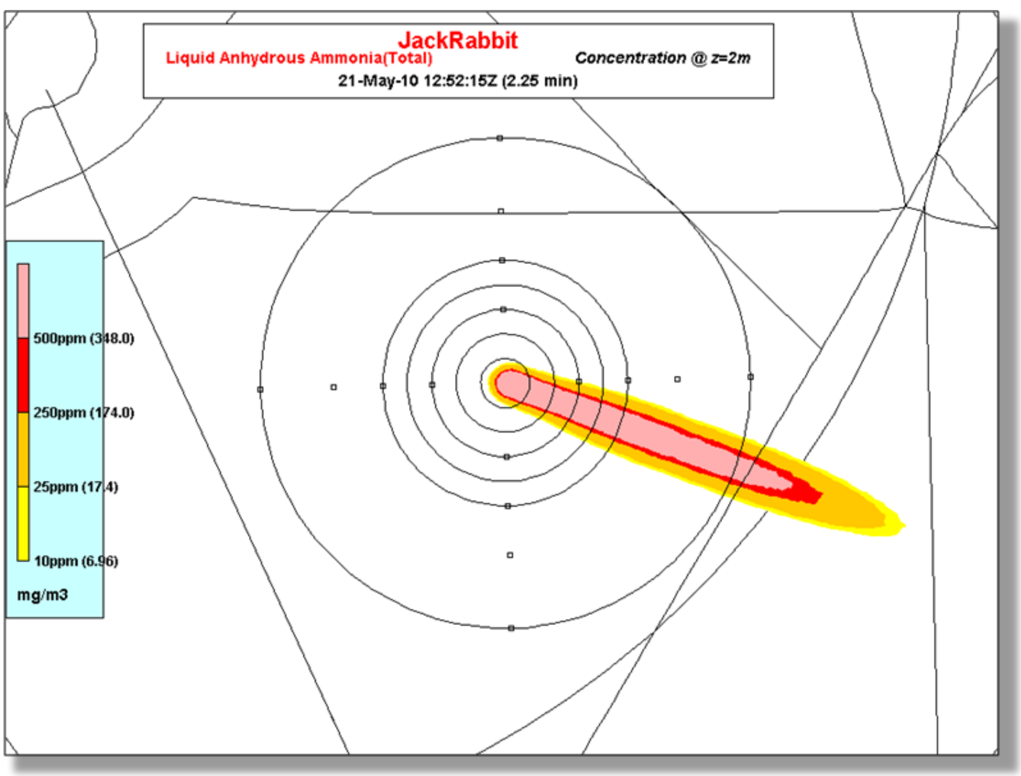

Figure 31c. Trial 10-RA HPAC Modeling at 135 Seconds After Dissemination

7.3 Downwind Effects Conclusions

Concentration data and data from other instrumentation were captured at distances greater than 100 meters from the source, representing a data profile that can be used to characterize the downwind cloud movement. This data will be analyzed in additional follow-on tasks to Jack Rabbit, which are planned to begin in FY 2011 when all datasets have been collected and made available.

In the absence of these analyses, only visual observations and pictures can be documented at this time. The best resource for documenting the observable behavior of the cloud being carried downwind is the set of video footage from several different cameras and angles. These video files are available upon request from the DHS CSAC. It is anticipated that comprehensive analyses in the planned follow-on studies will combine instrumentation data with the video footage to reveal an in-depth record and understanding of the chemical cloud and its downwind effects as it is transported and dispersed from the release site.

8.0 Instrumentation Performance Assessment

This section is provides documentation of the instrumentation performance observed during the Jack Rabbit test project. This is not intended to be an exhaustive review or analysis of the collected datasets. Comprehensive studies and analyses will be conducted through additional follow-on tasks which are planned to begin in FY 2011 when all datasets have been collected and made available.

8.1 General Performance

All teams from DPG and others participating in the Jack Rabbit test project reported successfully collecting data from the instrumentation that was deployed. Some groups reported damage to their instrumentation, particularly those instruments near the release site that were exposed to high concentrations of the released chemicals. The DPG Meteorology Division experienced approximately $77,000 in damaged or destroyed instrumentation, while the DPG Test Technology Division experienced approximately $21,000 in damages. Damages to instrumentation were almost entirely a result of exposure to corrosive chlorine gas, as evidenced by the fact that the failures were reported almost exclusively after chlorine releases. Chlorine gas is a very strong oxidizer, and it is known to extensively corrode any exposed metal surfaces in particular. Figure 32 shows evidence of corrosive damage sustained by some of the meteorological instrumentation.

Figure 32. Meteorological instrumentation showing evidence of corrosive damage

As the Jack Rabbit trials progressed, obvious performance degradation became apparent with some instrumentation, primarily after chlorine trials. The thermocouple network showed signs of diminished performance with each trial conducted. The video data coverage also experienced some performance issues, which are further discussed later in this section.

The DPG Test Technology Division evaluates emerging technologies for potential use in test projects at DPG. Because of this, some of the instrumentation deployed by this division was not fully tested prior to use on the Jack Rabbit test project. The UV Canary, UV Sentry, and Chemical Cloud Tracking System (CCTS) have been used on previous test projects at DPG, but not to the extent and exposure that they were subjected to during Jack Rabbit.

8.2 Meteorology

The 16 tripod-mounted and 15 tower-mounted portable weather instrumentation data system (PWIDS) that the DPG Meteorology Division deployed functioned very well. For datasets reviewed between 30 minutes prior to dissemination through 60 minutes after dissemination, the data retrieval rate for the tripod-mounted PWIDS was 99.73%. For that same period, the data retrieval rate for the tower-mounted PWIDS was 99.95%. Data from this instrumentation suite were collected 24 hours a day, 7 days a week for the duration of the Jack Rabbit test project. However, the statistics stated within this paragraph are for a 90 minute period of interest prior to, and during dissemination.

The DPG Meteorology Division deployed three 32-m towers with ultrasonic (sonic) anemometers mounted at 5 heights (2, 4, 8, 16, and 32 meters). All of these sensors functioned quite well. For datasets reviewed between 30 minutes prior to dissemination through 60 minutes after dissemination, the data retrieval rate for the sonics was 99.70%. Data from the towers were collected only during test days.

Two sonic anemometer stations were deployed within the Jack Rabbit depression during the record trials, but not for the pilot trials. It was assumed before the Jack Rabbit test project began that these instruments may be destroyed during the test. However, the sonic anemometers deployed in the depression not only survived, they were not even damaged. For datasets reviewed beginning 30 minutes prior to dissemination through 60 minutes after dissemination, the data retrieval rate for the sonics was 100%. Data from these sensors were collected only during test days.

The DPG Meteorology Division deployed 24 thermocouple arrays on the Jack Rabbit test project. The thermocouples functioned well, but their performance and/or reliability decreased with each trial conducted. The performance degradation was an observed characteristic, but will likely be supported by empirical statistics when quality assurance is performed on the datasets in planned follow-on studies. For

datasets reviewed beginning 30 minutes prior to dissemination through 60 minutes after dissemination, the data retrieval rate for the thermocouples was 96.03 overall, but the first two pilot trials experienced communication problems. During the first two pilot trials, the data retrieval rate was 85.49%, while the rate for the last eight record trials was 99.30%. After the first two trials, the communication problems were corrected by changing communication protocols. Data from the thermocouples were collected only during test days.

8.3 UV Canary

The DPG Test Technology Division deployed 20 UV Canaries during the Jack Rabbit test project. During the pilot tests, some corrosion occurred with the electronics due to improper sealing of the instrument. Also, the batteries proved to be inadequate to power the system for more than one hour after setup and low temperatures worsened the problem. Only 8 out of 20 systems provided a dataset during the pilot tests. Due to overexposure of chlorine on trial 02-PC, a few instruments had to be sent back to the manufacturer for refurbishing.

Power problems experienced during the pilot test were corrected during the record test trials by connecting two batteries in parallel. At the end of each test day, the batteries were collected and charged in a maintenance facility. Data collection during the record trials was also more reliable, however a few problems were still encountered. Several flash drives were defective, had poor connections, or failed during data archival. During the record trials, two UV Canaries were damaged due to overexposure to chlorine and two other systems required minimal maintenance after producing corrupt data.

Future tests would benefit by ensuring that an adequate power supply is ensured for the Canary instrumentation for much longer than the expected duration of the deployment. Spare inverters should be readily available, and flash drives should not be used for data storage. Although hard drive data storage is more costly than flash drive storage, it is also much more reliable. It was discovered that UV Canary performance varied from day to day. The UV Canary manufacturer provides an auto-calibration feature, but a manual calibration procedure should be developed to augment the auto-calibration process. A manual calibration conducted prior to each trial would determine the system's overall health and provide datasets with less variance.

8.4 UV Sentry

Three UV Sentries were deployed by the DPG Test Technology Division during the Jack Rabbit test program. During both of the pilot trials and several of the record trials, power was provided through inverters connected to batteries with solar charging. Even though the batteries were fully charged, the

inverters were observed to overheat and fail. In some cases, only one out of the three systems was functioning properly. Another problem discovered was that the raw dataset that was created could not be interpreted locally and it required post-processing by the manufacturer to be useful.

After detecting problems with the UV Sentry systems, corrections were made to the data collection process. Some of the corrections included software updates, corrected reference spectra, and modifications to the acquisition settings. The manufacturer again ran post-processing of the datasets after the corrections were made. Power was changed from the solar/battery/inverter arrangement to being supplied by small generators. After all of the corrections were incorporated into the UV Sentry data collection process, all data from the remaining trials were successfully collected.

8.5 Chemical Cloud Tracking System Using Fourier-Transform Infrared Spectrometers

The CCTS, which uses stand-off Fourier Transform Infrared (FTIR) spectrometers, was deployed by the DPG Test Technology Division. While this system allowed for tracking of the anhydrous ammonia clouds, it could not be used for the chlorine clouds because the chlorine molecule is not IR-active. Throughout the pilot and record trials, problems were encountered with the CCTS. The problems did not occur on every trial and every dataset, but some of them are noted below:

- Two systems lost GPS location, which made the resulting dataset unreliable.
- One system lost its background scan information, which resulted in an unreliable dataset.
- Two systems required system reboots around 0600 MST each morning, which was less than an hour before the planned trials
- One system lost its compass bearing after a reboot, which made the dataset unusable.
- Software errors occurred on two trials in which the GoogleMap® kml files could not be generated.

The DPG Test Technology Division corrected many of the problems encountered during the Jack Rabbit project, but several issues could not be resolved without extensive effort or assistance from the manufacturer. For the systems that lost GPS location parameters, this information was hard-coded into the equipment. Future test projects should require periodic verification of system parameters prior to, and during a test event. Vigilance in monitoring system malfunctions is needed with system reboots as necessary. Software issues were brought to the attention of the manufacturer with software upgrades expected prior to future test projects.

8.6 Bubblers

The bubblers deployed during the Jack Rabbit project were used to attempt to record an integrated dose of chlorine. When the bubbler data were compared with the data collected by the UV Canaries, DPG determined that the concentration of chlorine was significantly higher than what the bubblers could capture. Unfortunately, the upper limit of concentration that the bubblers can capture is unknown. The bubbler capture efficiency is reduced as the concentration of chlorine in the bubbler approaches the upper limit of its capabilities – the absorption coefficient for the bubbler sulfamic acid solution is too small to handle high concentrations of chlorine gas as it passes through the bubbler. Additionally, it is possible that the capacity of the bubblers was exceeded by the total dose of chlorine it was exposed to. There is a limited amount of sulfamic acid reactant available with which to capture the chlorine. Once this reactant is exhausted, the integrated dose recorded by the bubbler would be maxed out.

The bubbler capacity limitations could potentially be corrected in the future by sequencing the bubblers so that they would draw chlorine through them for a short period of time in series. Since individual bubbler operational time would be reduced, the amount of chlorine being captured would also be reduced. An added benefit to this technique is that a higher resolution concentration/time profile could be obtained. A disadvantage to this method may be that it would still not correct for the possibility that an erroneously low reported chlorine dose caused by an absorption coefficient that was too low for the high concentrations of chlorine.

Another way to correct for both capture efficiency and absorption coefficient problems would be to cascade the bubbler array. In a cascade, the chlorine would be drawn through a series of bubblers. If the chlorine is not captured in the first bubbler, it could be captured in the second, third, or fourth bubbler in series. Having bubblers configured in a cascade would capture the total mass of chlorine passing through the system.

The best configuration for determining concentration of chlorine may be to combine both the sequential and cascade methods. By combining techniques, not only would the capture efficiency and absorption coefficient problems be overcome, but a time profile would also possible. A drawback with this technique would be that it requires 16 times more bubblers, many more pumps, sequencing hardware/software, and a considerably larger data reduction effort than what was done on this test project. The added elements would equate to higher test costs and greater complexity, but a better dataset.

8.7 Video Coverage

Video surveillance was conducted from several cameras in varying formats during the Jack Rabbit project. Three high-definition cameras (HD) were operated at a distance of 2.5 km from grid center; these cameras functioned very well during the trials. Two standard-definition (SD) cameras were located on the rim of the depression basin at a distance of 25m from the dissemination, while two other SD cameras were mounted on 8m towers that were 50m from the release source. The depression basin and tower cameras were mounted in Plexiglas enclosures to protect them from overexposure to chemicals.

The depression basin and tower cameras provided adequate performance; however HD cameras should be used in future test projects. The microwave link that provided communication from the cameras to the command post (CP) experienced intermittent problems, especially when engulfed in a chemical cloud that could absorb the signal. This was especially noted during anhydrous ammonia trials. Also, the microwave system did not have a large enough bandwidth to transmit HD video for real-time observation at the CP. Prior to the conclusion of the Jack Rabbit project, the DPG Instrumentation Division procured a modern video transmission system that will accept HD signals, which would be very advantageous in future test projects.

8.8 Paper Detection

M8 and M9 paper, which are used to detect G- and V-nerve and H-blister agents, were deployed in the first two pilot trials for the Jack Rabbit test project. Neither paper showed any discernible difference to warrant their continued use for remaining Jack Rabbit trials.

A second paper detection method was investigated during the Jack Rabbit trials as a proof-of-concept experiment. Ordinary black construction paper was placed in stainless steel card holders throughout the Jack Rabbit test grid. The construction paper was observed to bleach to a lighter shade as a result of chlorine exposure. While this technique provides a good visual representation of the trial, it does not yet provide a quantitative dataset, as validation testing would be necessary to do so. However, the method demonstrated an inexpensive qualitative technique for determining which areas of the test grid experience high chlorine concentrations. This detection method was determined not to be effective for anhydrous ammonia during the anhydrous ammonia trials. Figure 33 shows the construction paper detection from the second pilot trial (02-PC) conducted on 08 April 2010.

Figure 33. Construction paper deployed 25m and 50m from the source, respectively

8.9 Three-Dimensional Cloud Analysis Visualization (3DCAV)

DPG provided 3D cloud visualization within 24 hours after each trial. The cloud visualization was created with data collected from SD and HD visible spectrum cameras, IR cameras, FTIR instrumentation, UV Sentries, and PWIDS. Some of the 24-hour 3DCAV video files appear erratic or laden with problems, but they were intended to be used only as a quick-look representation of what occurred during the trial. These files were not intended to be final cloud visualization products. It is possible for DPG to further process these files to make them more refined and a better representation of the actual test event. Figure 34 illustrates an anhydrous ammonia and chlorine cloud visualization using the 3DCAV system.

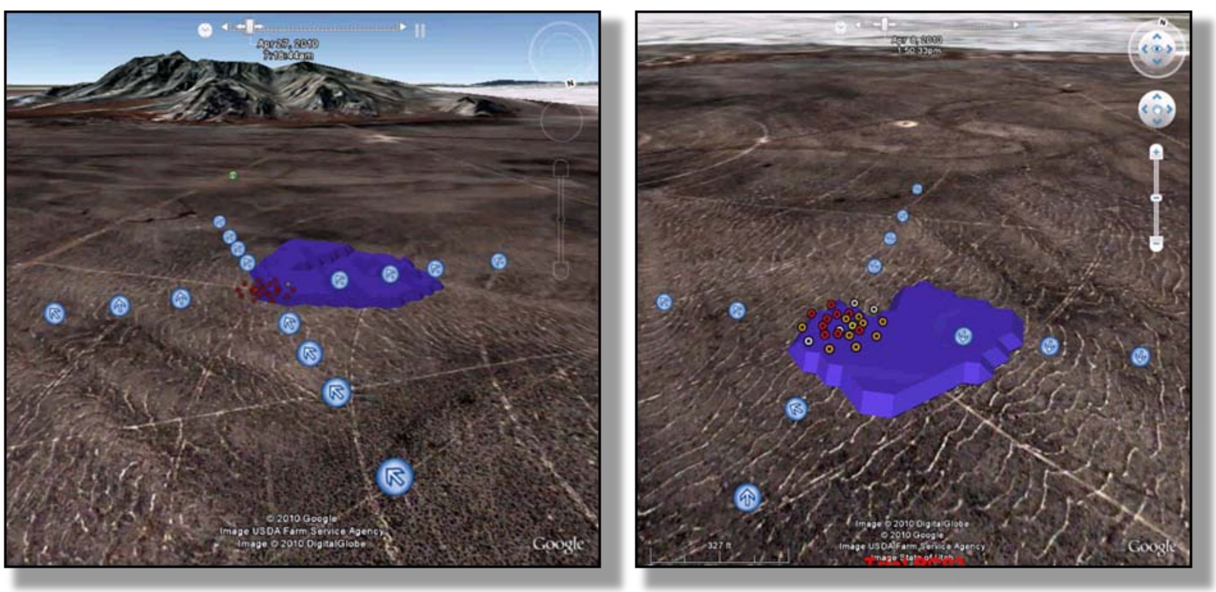

Figure 34. Anhydrous ammonia and chlorine cloud visualization, respectively

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9.0 Lessons Learned

This section provides a summary of lessons learned through the execution of the Jack Rabbit Test Project and provides recommendations for future test projects.

9.1 Cost Estimation

The cost estimate for the Jack Rabbit test project was accurate to within 1% of the actual expenses for the test project. Funding for the Jack Rabbit test project did not account for the possibility for test days lost to inclement weather, mechanical failures, or any other kind of cancelation of a test day. With the Jack Rabbit test, if the field test team gathered on the test grid to conduct a trial, the trial had to be executed because the funding and trial for that day were already committed. In other words, if the trial could not be executed, it was lost because there was not enough funding to compensate for gathering the test team for a second attempt at that same trial. Future test projects should provide funding for several test days in which the test team would not be able to conduct a trial, but the trial could be completed at a later date.

Some instrumentation during the Jack Rabbit test project was damaged or destroyed because of exposure to chemicals. Fortunately, the test days were actually shorter than expected and labor costs were saved because of this. Future test project budgets should include consideration of test project consumables as well as damaged and/or destroyed instrumentation.

Costs associated with design and construction of the dissemination system were much higher than anticipated. These higher costs were offset by lower costs in the chemical procurement than what was expected. Some of the increased costs for the dissemination system were because of safety features added to the valve assembly, but the majority of the increased costs came from the labor needed to construct a cradle sturdy enough to support not only the dissemination tank and system, but also the weight of the chemicals within the tank. Future test projects should be cognizant of the potential for higher than expected costs (i.e. – dissemination system, test grid preparation, chemical cost variance, etc.) and possibly add the inflated cost contingency into the cost estimation.

9.2 Scheduling

Test officers at DPG typically add 50% to 100% of time required to conduct a field test project to the test schedule. In other words, if a test is anticipated to take 4 days to complete, a test officer will schedule 6 to 8 days for the test execution. The additional time is necessary to compensate for delays in the test schedule. In the case of the Jack Rabbit program, the test grid was reserved until the last day of May 2010. However, the test project concluded 10 days earlier, on 21 May 2010.

Testing should be conducted whenever the weather is favorable. During the Jack Rabbit test, testing during favorable weather conditions was optimized. However, on one occasion testing should have continued through a weekend in which the weather conditions were ideal. After the last chlorine trial on Friday, 07 May 2010, the weather forecast for the following two days was favorable for the last anhydrous ammonia trials. However in order to allow for ample time for reconfiguring the test grid and instrumentation for anhydrous ammonia, the next trial was planned for Monday, 10 May 2010. Unfortunately, from 10 May 2010 to 19 May 2010, the weather conditions were not suitable for field testing because of continuous rain storms and the resulting degradation of the test grid due to mud and flooding of the depression basin. The poor weather conditions caused a delay in testing of nearly two weeks, which could have been avoided if the final two trials had been conducted on 08 and 09 May 2010. Scheduling impacts such as this are costly because they extend the stay by visiting test participants.

In the future, a minimum of 30 days should be scheduled between the pilot and record trials. In the case of the Jack Rabbit project, 3 weeks separated the two test phases because inclement weather delayed the start of the pilot trials. The Jack Rabbit test project did not require significant adjustments to the test process between the pilot and record trials, but larger test projects would likely require at least 30 days for test execution modifications after the pilot trials are conducted. The Jack Rabbit project experienced difficulty in the procurement/delivery of additional disseminator valves because of the short time duration between the pilot and record trials.

9.3 Environmental and Treaty Compliance

Prior to the start of the Jack Rabbit field campaign, environmental and treaty compliance issues had to be resolved. The DHS/TSA Environmental Office had concerns relating to the large outdoor release of chemicals, which the DPG Judge Advocate General (JAG) was able to quickly resolve before the situation caused any test project delays. Another incident that could have delayed the Jack Rabbit project involved chemical treaty compliance. The DPG Treaty Compliance Officer worked with the ECBC Treaty Compliance Office to diffuse a potential problem before it became a major issue. In both cases, good communications between DPG and the ECBC/CSAC team avoided potential problems early.

9.4 Meteorology/Climatology

Prior to the execution of Jack Rabbit field trials, DPG was tasked with conducting a climatology study of the proposed test site. A test site was selected meeting one of the test constraints of very low wind speeds. The meteorologists that conducted the climatology study and provided real-time downwind hazard modeling during the test execution became very familiar with the unique meteorological conditions of the

test site, even before any Jack Rabbit trials were performed. The DPG Meteorology Division supported the recommendation that due to the multi-directional possibility of the wind conditions, the sampling instrumentation should be deployed in a 360 degree configuration. This recommendation proved to be important for most of the trials. Forecasters outside of DPG attempted to predict a prevailing wind direction and velocity on several trials, but were generally unsuccessful. In one instance, wind speeds at the test site were low enough to conduct a trial, and were accurately forecast to be so by the DPG meteorologist on duty, while nearby locations had much stronger winds. The light wind conditions were accurately forecast to persist for only a short time, which was long enough for a successful test to be conducted. Overall, the expertise and local knowledge of the DPG meteorologists were critical to the success of the Jack Rabbit project. Lacking the years of experience with the DPG weather patterns which DPG meteorologists have attained, non-DPG forecasters, even recognized experts with long careers forecasting at other locations, are less capable of providing as reliable or timely information specific to the testing site. The DPG Meteorology Division should be the exclusive source of weather information guiding the design of future tests at DPG, and should be the primary advisor for the determination of instrumentation placement and release locations.

Future test projects at DPG should also consider the deployment of the DPG-owned miniSODAR and CTI Wind Tracer for a better understanding of the mid-level winds above the test grid. During the Jack Rabbit project, 32-m towers provided low level wind data, which was sufficient for this test project. However, if disseminated chemical quantities increase and test grid scaling grows, mid and upper level wind data will be required for accurate forecasting and downwind hazard prediction.

9.5 Instrumentation

All teams from DPG and others participating in the Jack Rabbit project reported successfully collecting data from the instrumentation that was deployed. As discussed in the previous section, several instruments and equipment experienced corrosion and performance degradation as a result of chlorine exposure (see Figure 33). Figure 35 shows the chemical damage incurred by the chlorine disseminator and knife gate valve.

Figure 35. Corrosion on chlorine disseminator and knife gate valve

Future test projects should take into consideration the corrosive nature of the disseminated chemicals and not only attempt to mitigate the destructive effects on sensing instrumentation, but also plan a study to determine how damaging these chemicals can be.

During the planning of the Jack Rabbit project, the ECBC/CSAC team made the recommendation that instrumentation near the release site be placed into positive-pressure enclosures to protect them from the exposure to the corrosive chemicals. The suggestion was not acted upon by DPG because of tight budgetary constraints. Because of the large loss of instrumentation that was ultimately experienced, this recommendation would have been far more cost effective than equipment replacement/repair. Most instrumentation was placed in air-tight, sealed enclosures, but this precautionary measure did not protect the equipment from damage. Future test projects should use the positive-pressure enclosures, which would add a minimal cost compared to instrumentation replacement. Use of these positive-pressure systems would involve including a small bottle of nitrogen in the enclosure, very slightly opened to create a long-lasting positive pressure.

9.5.1 UV Canaries

The UV Canary instruments deployed during Jack Rabbit experienced some problems due to corrosion from chlorine, battery power, and data storage issues. A detailed discussion of these issues is presented previously in this report, and can be found in Section 8.3.

9.5.2 UV Sentries

Three UV Sentries were deployed by the DPG Test Technology Division during the Jack Rabbit project. The instruments experienced various issues with software, configuration settings, and problems with the power supply. These issues were discussed in detail in Section 8.4 of this report, with recommendations for improved methodology for future tests.

9.5.3 Chemical Cloud Tracking System (CCTS)

The CCTS stand-off Fourier Transform Infrared (FTIR) spectrometers were deployed to track the anhydrous ammonia clouds during the Jack Rabbit trials. The CCTS could not track the chlorine clouds due to the fact that chorine is not an infrared-active molecule. Future tests involving chlorine could possibly include a tracer gas in the chlorine tank that is active in the infrared region of the spectrum, allowing for tracking of the cloud by the CCTS system. Additional issues and solutions for the CCTS system encountered at the Jack Rabbit trials were discussed in detail in Section 8.5 of this report.

9.5.4 Bubblers

The bubblers deployed during the Jack Rabbit project were used to attempt to record an integrated dose of chlorine, but experienced failure due to the high concentrations of chlorine overwhelming the capacity and absorption rate of the sulfamic acid solution. Possible solutions to these issues were discussed in detail previously in this report in Section 8.6.

9.6 Dissemination System

Chemical compatibility of valves and/or components used on the dissemination system became an issue during the Jack Rabbit t project. Figure 36 shows a ball valve that malfunctioned on the last Jack Rabbit trial (10-RA). It is recommended that future test projects that utilize valves for the dissemination of chemicals should use more expensive metallic valves. If non-metallic valves are used in future tests, they must be made out of polyvinyl chloride (PVC) for anhydrous ammonia tests and polytetrafluoroethylene (PTFE) (also known as Teflon®) or polyvinylidene fluoride (PVDF) for chlorine tests. The knife gate valve incorporated into the valve assembly during the Jack Rabbit project proved to be an excellent safety feature and it is strongly recommended that future test projects utilize this extra level protection for test participants.

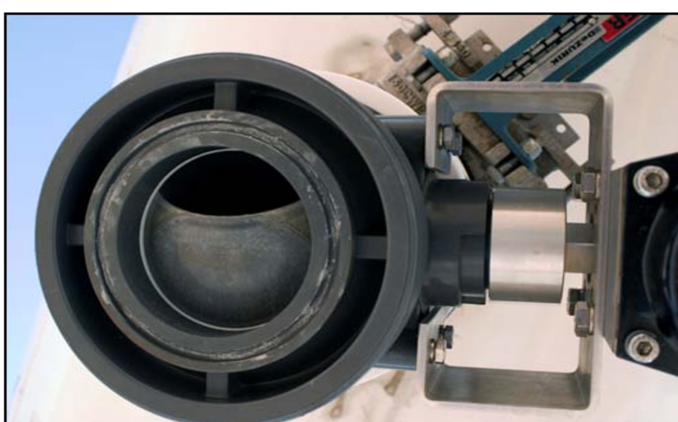

Figure 36. Ball valve used on Trial 10-RA that failed to close after release termination

During the Jack Rabbit trials, a considerable amount of activity was directed toward the dissemination system. The disseminator had to be deployed, filled, monitored, operated, and then prepared for the next trial. During all of this activity and personnel involvement, records of events were not always maintained. A data-logger system should be incorporated on the dissemination system for future test projects. With the data-logger, all activity associated with the disseminator would be recorded from the time it was deployed until the time it was removed from the test grid. Disseminator information would include the filling parameters, trial measurements, and post-trial data. Additionally it is recommended that the disseminator vapor temperature be measured; this was not done during the Jack Rabbit project.

The procurement lead-time for the valves used on the Jack Rabbit project was long. A long lead-time is typical with unique instrumentation and/or fixtures relating to testing. With the long lead time, it is recommended that future test projects start the procurement actions as soon as possible after the design phase is completed for the dissemination system or any other unique test fixture or instrumentation. The Jack Rabbit project experienced delays in the delivery of certain test items that could have potentially delayed the beginning of the field trials.

9.7 Video Footage

Standard definition (SD) video footage was recorded at multiple sites during the Jack Rabbit project. High definition (HD) footage was preferred, but not possible because of the bandwidth constraints of the microwave system that transmitted the video data to the command post. Since the Jack Rabbit project concluded, the DPG Instrumentation Division has procured a modern video transmission system that will accept HD signals. Future test projects should utilize HD cameras whenever and wherever possible for better video coverage of each trial.

Some video footage was lost due to camera malfunctions in early trials of the Jack Rabbit project. After the footage was lost, DPG installed video recorders at each camera position, as well as video recorders at the CP site. This redundancy helped ensure no additional loss in video data. Future test projects should continue this practice of recording redundancy to mitigate the potential of video data loss.

Some test projects have utilized high-speed video recording of disseminations. High-speed was not used on the Jack Rabbit test project because the dissemination occurred within a bowl-shaped depression and the camera did not have an adequate field of view at the distance that the camera had to be positioned. Because of the high cost of the high-speed camera, it would need to be positioned well beyond a hazardous zone during the release and at this distance, it would have had to been mounted on an

extremely tall tower to view into the depression. If future test projects disseminate on level terrain, a high-speed video recording of the dissemination is recommended.

9.8 Audio Recording

Future test projects should consider placing microphones and audio recording equipment close to the dissemination. With some of the anhydrous ammonia trials, it was difficult to determine the end of the release because the chemical cloud obscured the camera view of the valve. For the last Jack Rabbit trial, a HD camera with audio was used on one of the tower locations. Not only was the video quality from this camera superb, but the audio proved to be an added benefit. During the record chlorine trials, small eruptions within the depression were observed. Audio recording would have been useful during these trials to determine more information about these anomalous events.

9.9 Reporting

During the Jack Rabbit trials, a lot of activity was occurring at the command post. Because of this activity, it was difficult to record all significant events and conversations that were taking place at one time. Stenographers and/or audio recording equipment should be considered for future test projects.

Most test projects conducted at DPG require a standard set of documents. With the Jack Rabbit test project, monthly progress reports were required in addition to multiple reports after the field trials concluded. Since these additional reports fell outside the norm for standard reporting requirements, the additional labor and cost to produce the reports was underestimated. Future test projects with DPG should include considerations for more time and cost into report generation.

Data collected during the Jack Rabbit test project took much longer to quality control and package than what was initially anticipated. The DPG dataset was provided during the Jack Rabbit debriefing meeting conducted in Salt Lake City, UT on 14 June 2010. Datasets from other test participants took several months before being delivered. Future test projects should set more feasible timelines for data delivery, and agreements with additional test participants should specify penalties for extremely late data delivery.

9.10 Conclusions

DPG and the ECBC/CSAC team established a professional and productive working relationship during the Jack Rabbit project. DPG managed the field test campaign and provided the field test experience/expertise that has made it a premier test center for over half a century. The ECBC/CSAC team

provided program management and recruited several outside organizations to augment the DPG workforce, which proved advantageous to the success of the Jack Rabbit project.

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APPENDIX A: TEST DIRECTIVE

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Test Directive

Table A.1. 2010-DT-DPF-SNIMT-E5835 (METHODOLOGY (DT)) Jack Rabbit Project

SYSTEM	METHODOLOGY
Test Title	Jack Rabbit
Authorize Test Center to Work	Activation in ADSS constitutes authority to begin planning IAW Project: 2010-DT-DPG-SNIMT-E5835. Upon receipt of this directive, immediately review the test milestone schedule in light of known other workload and projected available resources. If rescheduling is necessary and the sponsor non-concurs, forward a memorandum citing particulars, together with recommendations, to HQ, DTC (ATTN: DTC Test Manager) within 15 days after receipt of this directive. Reschedules concurred in by the sponsor can be entered directly by the Test Center. Test Execution is authorized after approval of Test Plan (TP)/Detailed Test Plan (DTP) and conduct of Test Readiness Review (TRR).
Scope of Work	The objective of Jack Rabbit is to (a) develop and evaluate a mechanism for the controlled, rapid release of liquefied, pressurized gases from containment to approximate the conditions hypothesized to generate a persistent vapor-aerosol cloud in a 90-ton railcar release; (b) characterize the vapor/aerosol cloud movement, behavior, and physiochemical characteristics and compare those characteristics with known observations and testing of large-scale releases of the testing materials; (c) determine if ammonia and/or R-134a can potentially act as less expensive and less dangerous dense gas for studying the component phenomena of large scale releases of dense gas TIH materials; and (d) field and evaluate instrumentation that can be used for the study of the large-scale release of the testing materials, and develop and evaluate testing methodology for future additional and potentially larger-scale tests.
Test Documentation	Plan/Report Final Approval (check one): _X_ TC ___HQ
	Plans and Reports will be IAW with the ADSS milestones and DTC Pam 73-1. Test plans need to be approved prior to the start of test. Maximum use of TOPS/ITOPS must be followed during test planning.
Storage and Location of Test Documents and Data	Unclassified plans/reports/data will be uploaded to the VISION Digital Library per DTC PAM 73-1.
References	List all references to support creation of Detailed Test Plan/Test Plan, to include any Safety, Security and Environmental documents:
Special Considerations: Safety	All Safety considerations will be met and strictly adhered to.
Special Considerations: Environmental	All Environmental considerations will be met and strictly adhered to. Environmental documentation has been requested, in writing, from the test sponsor and will be provided upon receipt and review by HQ DTC. In the interim, site-specific environmental documentation should be prepared and concurrence obtained from the Test Center Environmental Office. Immediately contact the Safety and Environmental Risk Management Division, Directorate for Range Infrastructure and Investments, HQ DTC, DSN: 298-1084/1077, if lack of sponsor-developed documentation results in significant data gaps which preclude the preparation of such documentation.
Special Considerations: Security	All Security considerations will be met and strictly adhered to.
Distribution	POC: Mr. Adolfo R. Negron Email: adolfo.r.negron@us.army.mil
Point of Contact	Mr. Clipper Clowes Email: William.Clowes@us.army.mil

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APPENDIX B: Instrumentation

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B.1 Background

Instrumentation for the Jack Rabbit Test Program falls into one of three basic categories: photonic, chemical, or meteorological. Each category consists of multiple types of instrumentation. Figure B.1 is a photograph taken from the east 8 m tower which shows instrumentation from all three categories. In both the photonic and chemical categories, a further division is required for either the chlorine or the anhydrous ammonia detection.

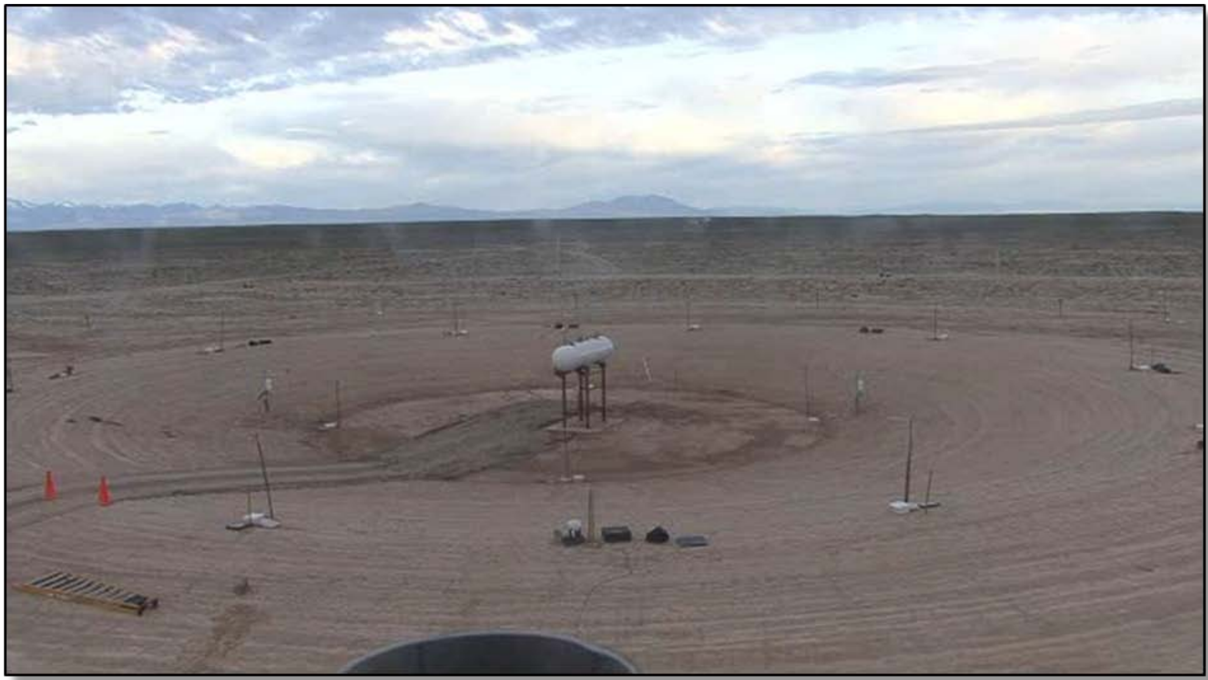

Figure B.1. Instrumentation Surrounding Disseminator at Grid Center – Jack Rabbit Project

Photonic support consisted of recording visual spectrum footage for both anhydrous ammonia and chlorine disseminations, but IR footage was used only for anhydrous ammonia releases.

Chemical detection falls into one of two categories: point detection or stand-off detection. All chemical detection occurred within a 500 m radius of the grid center. WDTC provided the majority of chemical detection; however, CSAC contracted with CTEH and SSLLC to augment the WDTC dataset. Several types of chemical detection sensors were collocated to support instrument inter-comparison.

An extensive meteorological dataset was collected during Jack Rabbit. The dataset consisted of surface data, vertical profiles up to 32 m, sonic anemometer data, and thermocouple data.

The instrument numbering convention followed the same numbering sequence as a standard analog clock. The Northern-most position on a ring is the highest number on that ring, similar to the 12 on a clock. Conversely, the lowest number on the ring is just to the right of the highest number, similar to the 1 on a clock. Instrument types that are located on multiple rings begin the numbering sequence on the innermost ring and spiral outward in ascending order. This numbering convention is applicable throughout this document, unless otherwise specified. An example of the numbering convention is provided in Figure B.2.

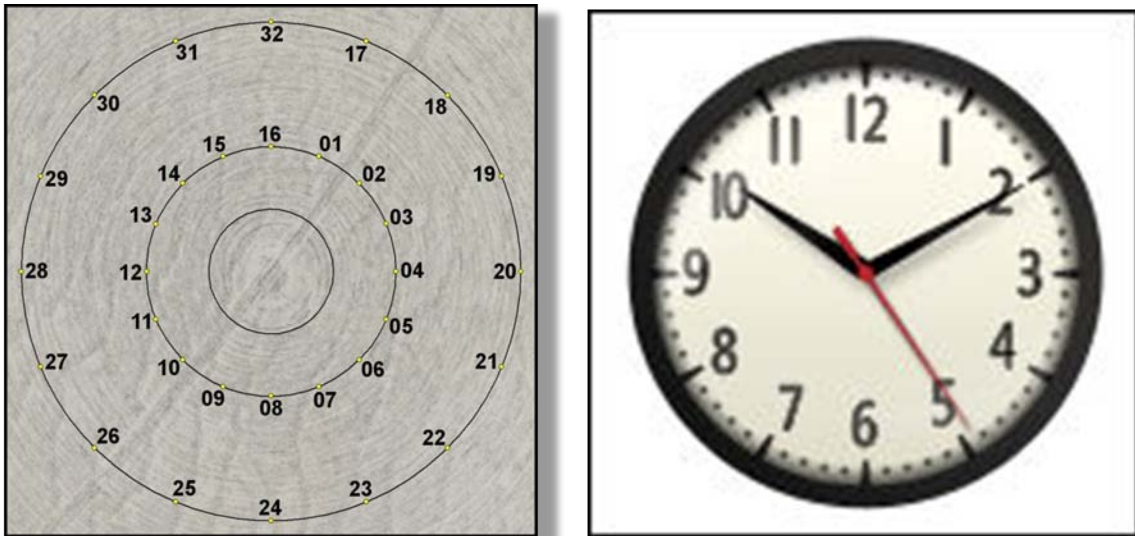

Figure B.2. Instrument Numbering Convention Compared With a Clock – Jack Rabbit Project

B.2 IR VIDEO COVERAGE

Three Orion 890 very longwave (VLW) radiometers (Sofradir EC, Inc., Fairfield, New Jersey) were deployed at positions located 1250 m from the grid center. The positions were approximately 120 degrees offset from each other; however, they had to be located on evacuation routes. On 30 April 2010, the camera positions were relocated to 2500 m from grid center at 120 degree offsets for the safety of the camera operators. The original camera positions prior to 30 April 2010 are illustrated in Figure B.3, and the geodetic locations for Trials 01-PA through 03-RA are provided in Table B.1.

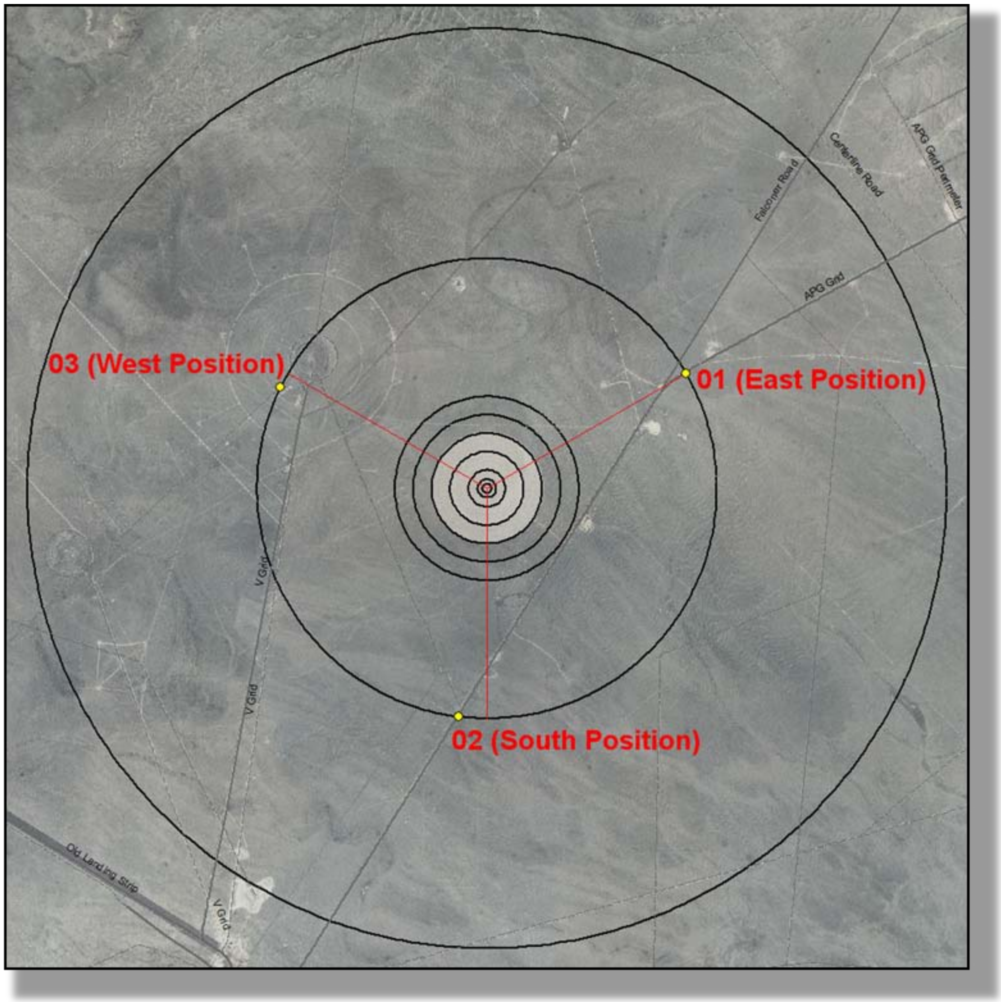

Figure B.3. Infrared and Visual Cameras Located 1250 m From Grid Center – Jack Rabbit Project

Table B.1. Infrared and Visual Camera Geodetic Locations – Jack Rabbit Project

INFRARED AND VISUAL CAMERA GEODETIC LOCATIONS	LATITUDE	LONGITUDE
1250 m from Grid Center (Prior to 30 April 2010 - Trials 01-PA[a] through 03-RA[a])		
01 (East Position)	40.2124905437	-113.253197380
02 (South Position)	40.1954114522	-113.267144367
03 (West Position)	40.2112904482	-113.279081334
2500 m from Grid Center (After 30 April 2010 - Trials 04-RA[a] through 10-RA[a])		
01 (East Position)	40.218257	-113.240588
02 (South Position)	40.184117	-113.266782
03 (West Position)	40.217564	-113.291995

[a]Trial names are identified as follows: the first two digits are the trial sequence number; the first letter is the trial type (P = pilot, R = record); the second letter is the chemical type (A = ammonia, C = chlorine).

Digital video streams of data that are time stamped were recorded onto digital data recorders located at the manned positions where the tracking systems were operated. Inter-Range Instrumentation Group, Code B (IRIG-B) time was stamped onto all video and tracker orientation recorded data, which were further posttest processed to generate cloud dimensional and positional information of the cloud plumes. The Orion radiometer IR longwave (LW) video systems (7.7 to 11.5 um) recorded the cloud plume signatures generated for the anhydrous ammonia disseminations. All clouds were tracked using photonics optical data techniques from the start of the release until the majority of the cloud mass signature could no longer be detected or was no longer visualized. The radiometer can record the anhydrous ammonia signatures in day or night conditions.

A tracking system was interfaced with control computers to record the azimuth and elevation. These video streams are processed through the Temporally Rendered Automatic Cloud Extraction (TRACE) system to generate two-dimensional (2D) cloud contours and 2D geometric data of the cloud plume. The data are then processed in the 3 Dimensional Cloud Analysis and Visualization systems (3DCAV) where a three-dimensional (3D) model is generated and overlaid onto a special visual presentation application designed to render and outline the 3D cloud onto a Google™ Earth (Mountain View, California) map with other ground-truth instrumentation results.

B.3 VISUAL SPECTRUM VIDEO COVERAGE

Video cameras mounted on top of the three tracking systems (collocated with IR cameras) recorded the chlorine cloud plume signature in the visible spectrum (.4 to 1.0 µm). The positions were approximately 120 degrees offset from each other and were located on evacuation routes. The original camera positions (prior to 30 April 2010 - Trials 01-PA through 03-RA) are illustrated in Figure B.3, and the geodetic locations for all of the trials are provided in Table B.1. The visible camera systems required an adequate amount of available scattered sunlight to record the chlorine signature in the visible spectrum. An assortment of optics was available for each visible camera system to match the required fields of view at the prescribed estimated safe standoff distances. The visible cameras use charge-coupled device (CCD) chip sets and are categorized as high-resolution systems that provide 570 lines of resolution. HD cameras (720i resolution) were available with a variety of optics to record the chlorine signature. Initially, visible video coverage was recorded at a standoff distance of 1250 m from grid center and later at a distance of 2500 m from grid center.

Standard video was recorded from two 10 m towers located at a 90-degree offset from each other and at a standoff distance of 50 m from the grid center. WDTC also provided video coverage on the edge of the depression, which was 25 m from the grid center, with two standard video cameras. These two cameras were protected from chemical exposure by being placed in sealed enclosures. The camera positions are illustrated in Figure B.4, and the geodetic locations are provided in Table B.2.

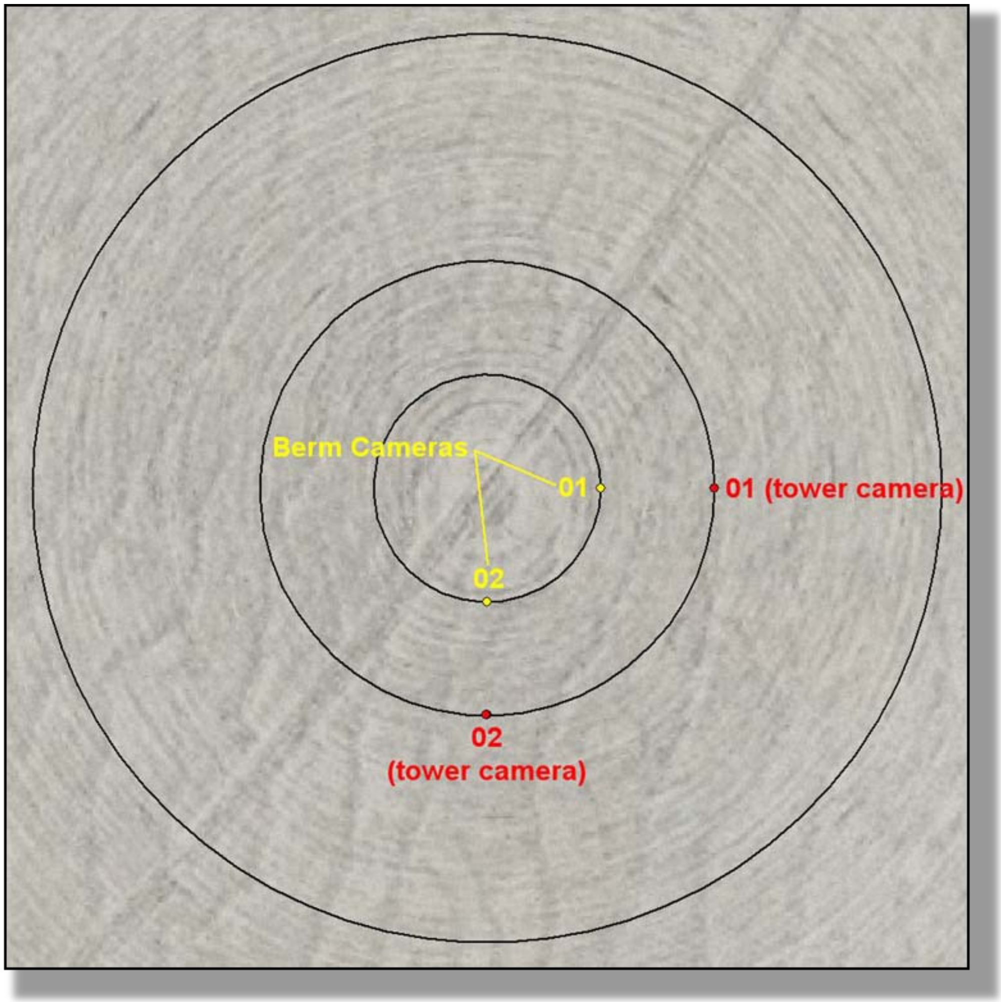

Figure B.4. Inner Camera Positions Located on Berm (25 m) and Towers (50 m) – Jack Rabbit Test Project

Table B.2. Inner Camera Geodetic Locations on Berm (25 m) and Towers (50 m) – Jack Rabbit Project

INNER CAMERA POSITIONS	LATITUDE	LONGITUDE
01 (East Berm)	40.2066215350	-113.265427974
02 (South Berm)	40.2063913949	-113.265714001
01 (East Tower)	40.2066272839	-113.265134438
02 (South Tower)	40.2061663562	-113.265708486

B.4 FOURIER-TRANSFORM INFRARED SPECTROMENTER

The scanning Fourier-Transform Infrared (FTIR) spectrometers are a system of sensors that communicate wirelessly to a control personal computer to provide concentration maps and concentration-pathlength (CL) data. They are passive optical devices sensitive to radiation in the 7- to 13-μm portion of the spectrum. The sensors can scan either a predefined area or automatically track a plume. FTIRs were used during the anhydrous ammonia trials.

During Jack Rabbit, three FTIRs were placed 500 m from the grid center at 120-degree offsets to one another. Two additional FTIRs were deployed on the 1250 m ring and were collocated with IR/visual camera positions 01 (east position) and 03 (west position). The FTIR positions are illustrated in Figure B.5, and the geodetic locations are provided in Table B.3.

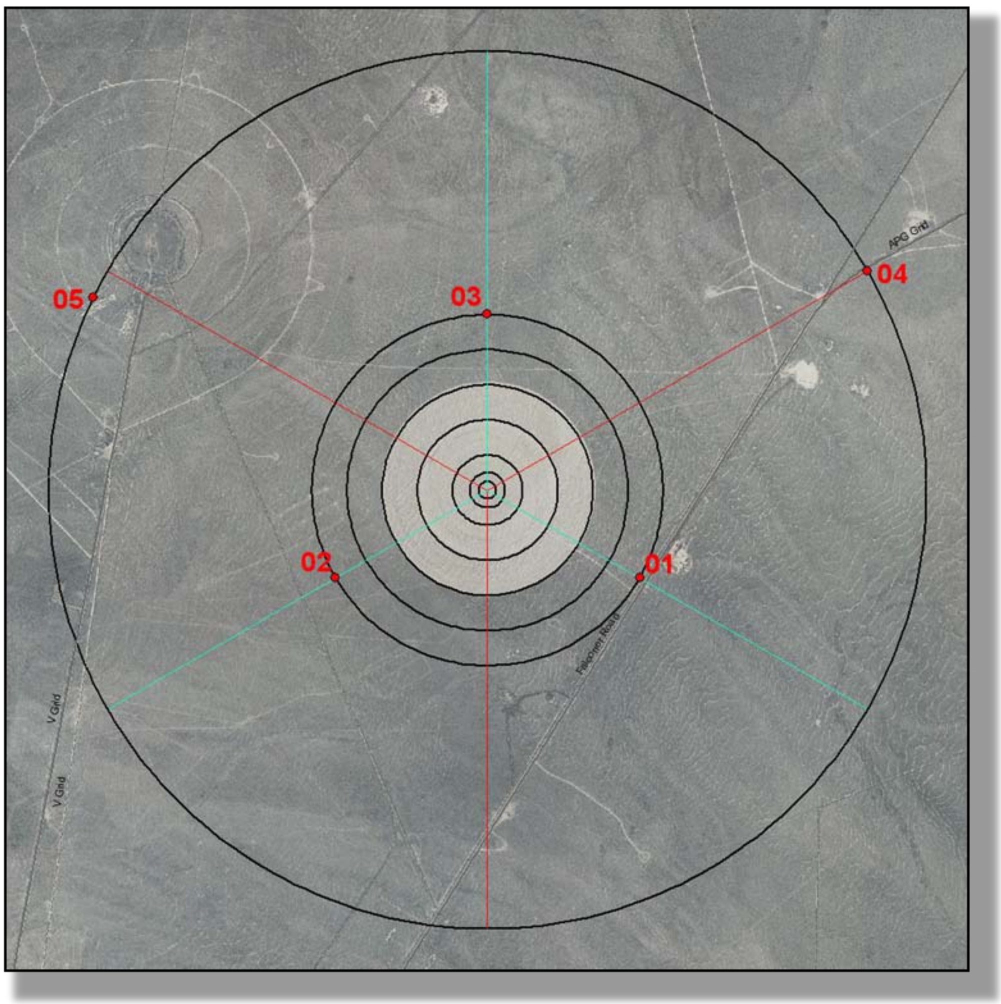

Figure B.5. Fourier-Transform Infrared Positions Located 500 m and 1250 m From Grid Center – Jack Rabbit Project

Table B.3. Fourier-Transform Infrared Geodetic Locations 500 m and 1250 m from Grid Center – Jack Rabbit Project

FTIR[a] POSITIONS	LATITUDE	LONGITUDE
01 (East 500 m)	40.2044647419	-113.260562829
02 (West 500 m)	40.2042659107	-113.270729528
03 (North 500 m)	40.2111169822	-113.265871468
04 (East 1250 m)	40.2124905437	-113.253197380
05 (West 1250 m)	40.2112904482	-113.279081334

[a] FTIR = Fourier-transform infrared

B.5 ULTRAVIOLET SENTRY

The Cerex Ultraviolet (UV) Sentry is an UV standoff detector capable of operating at standoff distances (distance between source and detector) over 1000 m and detecting path-integrated concentrations from 3 to 10,000 parts-per-million (ppm) of chlorine. A xenon arc lamp serves as the source, and the receiver uses collection optics to focus the UV light to a fiber optic which is sent to the spectrometer. The system is capable of wireless operation. Currently, WDTC has three Cerex UV Sentries that were deployed on the Jack Rabbit test. The UV Sentry was used for chlorine detection and not for anhydrous ammonia.

The UV Sentry was collocated with the FTIRs at locations 01, 02, and 03, which are spaced at 120-degree increments. The numbering sequence is the same as for the FTIRs. A photograph of the UV Sentry is provided in Figure B.6, and the geodetic coordinates are provided in Table B.4.

Figure B.6. Cerex Ultraviolet Sentry – Jack Rabbit Project

Table B.4. Cerex Ultraviolet Sentry Positions Collocated With Fourier-Transform Infrared at 500 m From Grid Center – Jack Rabbit Project

UV SENTRY RECEIVER POSITIONS	LATITUDE	LONGITUDE
01 (East 500 m)	40.2044647419	-113.260562829
02 (West 500 m)	40.2042659107	-113.270729528
03 (North 500 m)	40.2111169822	-113.265871468
UV SENTRY SOURCE POSITIONS		
East Receiver	40.2087662990	-113.270879801
West Receiver	40.2089656787	-113.260712415
North Receiver	40.2021152360	-113.265571689

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B.6 ULTRAVIOLET CANARY

The Cerex ultraviolet (UV) Canary is a dedicated chlorine point detector. The instrument was designed to be operated under extreme desert conditions (0 to 40 °C) with an operational concentration range of 10 to 10,000 ppm of chlorine. The Canary samples air through a Teflon® tube into a gas cell where a specialized light-emitting diode (LED) source is used to measure concentration. The system is capable of wireless operation. Currently, WDTC has 20 of these units that were deployed on the Jack Rabbit test. The UV Canary sampled at 1 m above ground level (AGL) and was used exclusively for chlorine detection.

The UV Canary configuration consisted of instruments placed at 22.5-degree increments at a distance of 50 m from the grid center. At a distance of 100 m from grid center, the UV Canary was deployed at 45-degree increments. A photograph of the Cerex UV Canary is provided in Figure B.7, the positions are illustrated in Figure B.8, and the geodetic coordinates are in Table B.5.

Figure B.7. Cerex UV Canary – Jack Rabbit Project

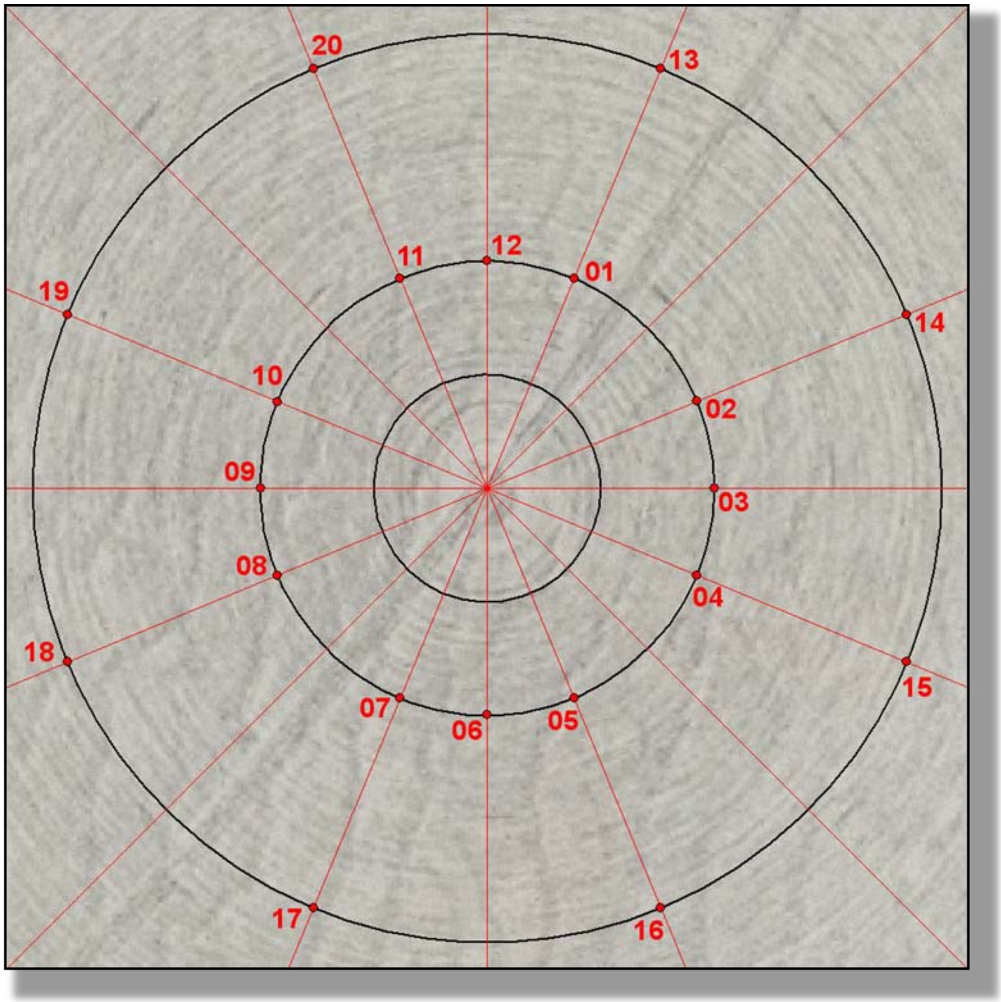

Figure B.8. Cerex Ultraviolet Canary Positions Located 50 m and 100 m From Grid Center – Jack Rabbit Project

Table B.2. Cerex Ultraviolet Canary Geodetic Locations 50 m and 100 m From Grid Center – Jack Rabbit Project

ULTRAVIOLET CANARY POSITIONS	LATITUDE	LONGITUDE
01 (Upper Northeast, 50 m)	40.2070355012	-113.265510950
02 (Lower Northeast, 50 m)	40.2067985486	-113.265185113
03 (East 50 m)	40.2066272687	-113.265134436
04 (Upper Southeast, 50 m)	40.2064541953	-113.265173665
05 (Lower Southeast, 50 m)	40.2062048335	-113.265483283
06 (South 50 m)	40.2061663465	-113.265706542
07 (Lower Southwest 50 m)	40.2061962625	-113.265931955
08 (Upper Southwest 50 m)	40.2064332695	-113.266257066
09 (West 50 m)	40.2066043097	-113.266307372
10 (Lower Northwest 50 m)	40.2067770799	-113.266268520
11 (Upper Northwest 50 m)	40.2070265066	-113.265959598
12 (North 50 m)	40.2070658947	-113.265736502
13 (Upper Northeast 100 m)	40.2074559209	-113.265300085
14 (Lower Northeast 100 m)	40.2069811640	-113.264649219
15 (Upper Southeast 100 m)	40.2062927965	-113.264626312
16 (Lower Southeast 100 m)	40.2057932212	-113.265244686
17 (Lower Southwest 100 m)	40.2057756321	-113.266142946
18 (Upper Southwest 100 m)	40.2062503588	-113.266793774
19 (Lower Northwest 100 m)	40.2069387262	-113.266816720
20 (Upper Northwest 100 m)	40.2074383245	-113.266198338

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B.1 Jaz Ultraviolet-Visible (Ocean Optics Inc., Dunedin, Florida)

CSAC contracted with SSLLC to provide additional point chemical detection to augment the WDTC dataset. The contract also targeted the test objective of evaluating instrumentation for future large-scale releases. The SSLLC-owned and operated Ocean Optics Jaz Ultraviolet-Visible (UV-VIS) Sensor was used as a point detector during the Jack Rabbit test conduct, but it was not deployed for the Jack Rabbit pilot test. The instrument can be used for both anhydrous ammonia and chlorine detection, and the approximate detection range is 100 to 10,000 ppm. SSLLC provided CSAC with an instrumentation plan[4] that outlines their involvement in the Jack Rabbit Project and provides information relating to the Jaz UV-VIS sensor.

The Jaz UV-VIS configuration consisted of instruments placed at 45-degree increments at a distance of 25 m and 50 m from the grid center. Positions for the Jaz UV-VIS sensors are illustrated in Figure B.9, and the geodetic coordinates are in Table B.6.

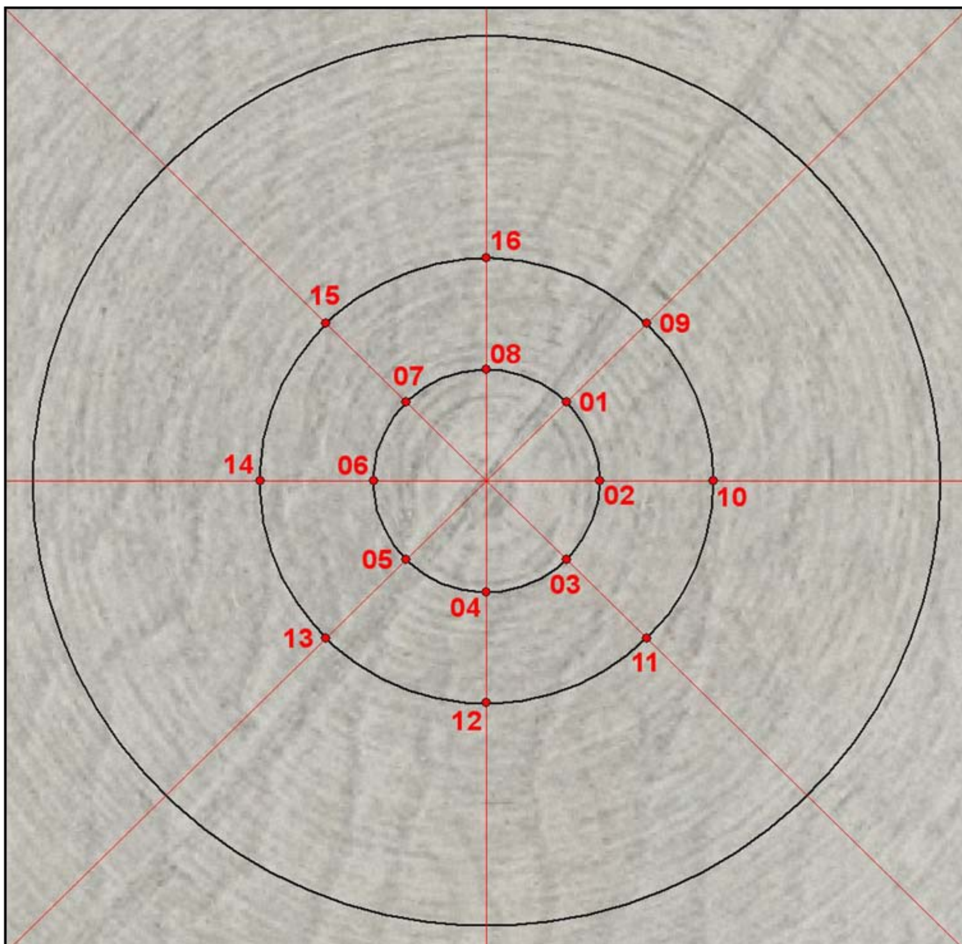

Figure B.9. Jaz Ultraviolet-Visible Detectors Located 25 m and 50 m From Grid Center – Jack Rabbit Project

Table B.3. Jaz Ultraviolet-Visible Canary Geodetic Locations 25 m and 50 m From Grid Center – Jack Rabbit Project

JAZ UV-VIS POSITIONS	LATITUDE	LONGITUDE
01 (Northeast 25 m)	40.2067783658	-113.265520013
02 (East 25 m)	40.2066215215	-113.265427972
03 (Southeast 25 m)	40.2064612870	-113.265509442
04 (South 25 m)	40.2063913936	-113.265714025
05 (Southwest 25 m)	40.2064528435	-113.265923396
06 (West 25 m)	40.2066100534	-113.266013861
07 (Northwest 25 m)	40.2067705661	-113.265934006
08 (North 25 m)	40.2068408341	-113.265729004
09 (Northeast 50 m)	40.2069418915	-113.265317349
10 (East 50 m)	40.2066272687	-113.265134436
11 (Southeast 50 m)	40.2063058995	-113.265296165
12 (South 50 m)	40.2061663465	-113.265706548
13 (Southwest 50 m)	40.2062899929	-113.266125251
14 (West 50 m)	40.2066042993	-113.266307372
15 (Northwest 50 m)	40.2069253384	-113.266146403
16 (North 50 m)	40.2070658947	-113.265736502

B.8 RAE® Systems (RAE® Systems, San Jose, California)

CSAC contracted with CTEH to provide additional point chemical detection to augment the WDTC dataset. The objective of instrumentation evaluation was also satisfied with the CSAC/CTEH contract. CTEH-owned and operated several AreaRAE point detectors during the Jack Rabbit test conduct. Also deployed by CTEH were many DPG-owned MiniRAE point detectors. Both the AreaRAE and MiniRAE are photoionization detectors (PIDs) capable of ammonia and chlorine detection. The AreaRAE has an approximate detection range of 100 to 10,000 ppm, while the miniRAE has a detection range of 0 to 10,000 ppm.

CTEH deployed the RAE detectors in an optimized configuration based on wind direction and wind speed. Because of meteorological conditions at the time of dissemination, the best configuration was often a 360-degree instrumentation deployment. CTEH will provide CSAC with a data report and geodetic coordinates for instrumentation deployment for each of the Jack Rabbit trials.

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B.9 BUBBLERS

The bubbler systems consist of Teflon® impingers with vertical and side ports filled with 0.1 percent sulfamic acid. The bubblers are attached to radio-controlled vacuum pumps with Teflon® tubing. The flow of the vacuum is controlled by critical orifices. Glass frits attached inside the bubblers break up the bubbles as air is passed through the bubbler to allow for more interaction between the bubbles and the sulfamic acid. The method to capture the test gas using the bubblers is based on the Occupational Safety and Health Administration (OSHA) Inorganic Method ID-101.[5] After each trial, sulfamic acid solutions were transported to the laboratory where the samples were weighed to compare the mass before and after the sampling in the field during the test. The solutions were then transferred to glass sampling jars and stored in the freezer to await analysis.

The capture efficiency of the WDTC bubbler system was tested in the laboratory by bubbling 5000 ppm test gas through a system of two bubblers where the test gas passed through the two bubblers in series for 1 minute. The first bubbler was analyzed resulting in 4890 ppm, which is an 97.8 percent capture efficiency. There was very little test gas captured in the second bubbler.

WDTC has 70 bubblers that were used in the tests. Of the 70 bubblers, 32 were deployed for each trial and 3 were reserved as spares, while the other 35 were in the chemical laboratory being analyzed. This process allowed for trials to be conducted every day with no down days for data analysis.

During the tests, bubblers were deployed at 50 m, and 100 m from the grid center at 22.5-degree increments. Sampling occurred at a height of 1 m. The bubbler positions are illustrated in Figure B.10, and the geodetic locations are in Table B.7.

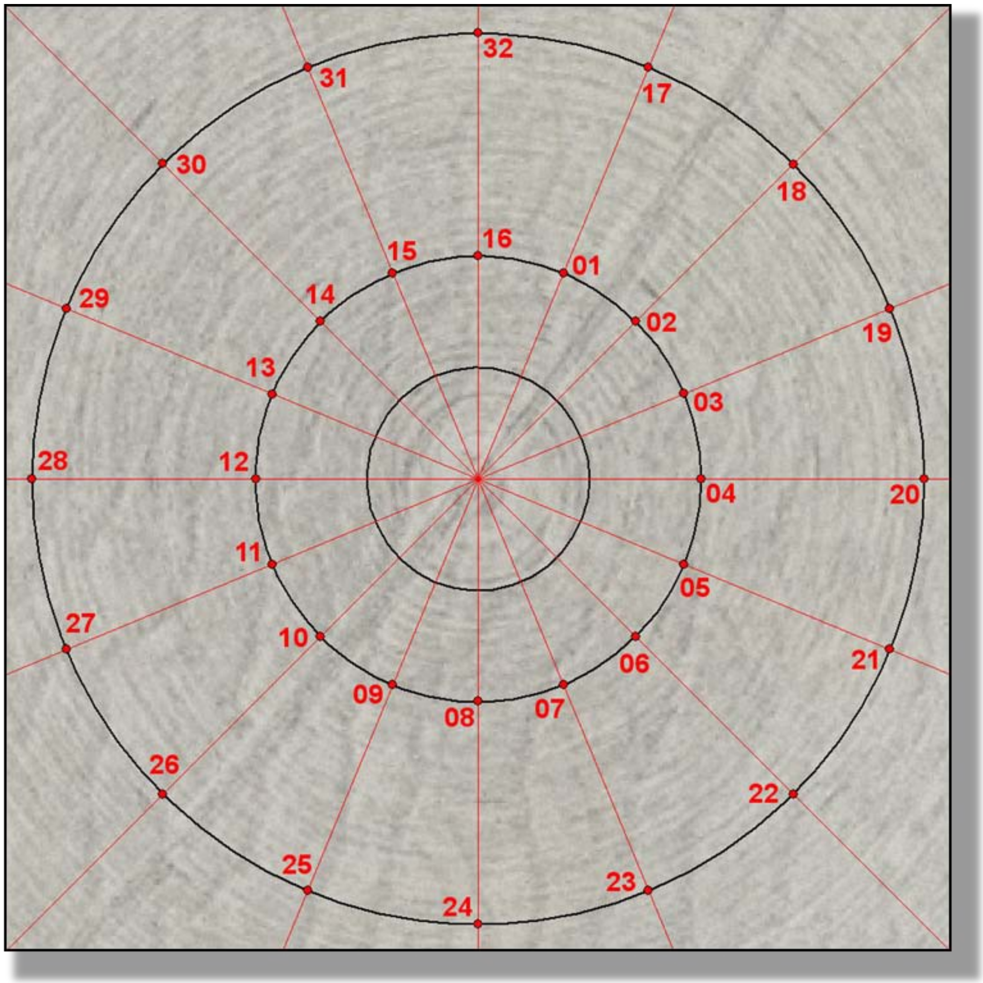

Figure B.10. Bubbler Positions Located 50 m and 100 m From Grid Center – Jack Rabbit Project

Table B.4. Bubbler Geodetic Locations 50 m and 100 m From Grid Center – Jack Rabbit Project

BUBBLER POSITIONS	LATITUDE	LONGITUDE
01 (North Northeast 50 m)	40.2070355012	-113.265510950
02 (Northeast 50 m)	40.2069418894	-113.265317346
03 (East Northeast 50 m)	40.2067985486	-113.265185113
04 (East 50 m)	40.2066272687	-113.265134436
05 (East Southeast 50 m)	40.2064541953	-113.265173665
06 (Southeast 50 m)	40.2063059112	-113.265296149
07 (South Southeast 50 m)	40.2062048335	-113.265483283
08 (South 50 m)	40.2061663465	-113.265706542
09 (South Southwest 50 m)	40.2061962625	-113.265931955
10 (Southwest 50 m)	40.2062900000	-113.266125260
11 (West Southwest 50 m)	40.2064332695	-113.266257066
12 (West 50 m)	40.2066043097	-113.266307372
13 (West Northwest 50 m)	40.2067770799	-113.266268520
14 (Northwest 50 m)	40.2069253241	-113.266146420
15 (North Northwest 50 m)	40.2070265066	-113.265959598
16 (North 50 m)	40.2070658947	-113.265736502
17 (North Northeast 100 m)	40.2074559209	-113.265300085
18 (Northeast 100 m)	40.2072680970	-113.264913064
19 (East Northeast 100 m)	40.2069811640	-113.264649219
20 (East 100 m)	40.2066387608	-113.264547365
21 (East Southeast 100 m)	40.2062927965	-113.264626312
22 (Southeast 100 m)	40.2059959473	-113.264870689
23 (South Southeast 100 m)	40.2057932212	-113.265244686
24 (South 100 m)	40.2057164371	-113.265691593
25 (South Southwest 100 m)	40.2057756321	-113.266142946
26 (Southwest100 m)	40.2059634097	-113.266529889
27 (West Southwest 100 m)	40.2062503588	-113.266793774
28 (West 100 m)	40.2065927745	-113.266895648
29 (West Northwest 100 m)	40.2069387262	-113.266816720
30 (Northwest 100 m)	40.2072356165	-113.266572313
31 (North Northwest 100 m)	40.2074383245	-113.266198338
32 (North 100 m)	40.2075160156	-113.265751497

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B.10 Portable Weather Information and Display System

The WDTC-developed Portable Weather Information and Display System (PWIDS) consists of mobile meteorological measurement stations capable of collecting and displaying weather information at a predetermined rate. Each station consists of a tripod-mounted propeller-vane wind monitor, a temperature/humidity sensor mounted in a naturally aspirated radiation shield, a data logger, an optically isolated RS-232 interface, and a spread-spectrum radio/modem. Power is supplied by a solar panel and battery combination.

Typically, the measurement height is 2 m AGL, with sensors on a standalone tripod, although PWIDS can be mounted at various elevations on towers. In most uses, the PWIDS data acquisition rate is 1 hertz (Hz), and the data collected are averaged to 10-sec intervals. Accuracies of the R.M. Young 05103 Wind Monitor (R.M. Young Company, Traverse City, Michigan) are ±0.2 m/s^{-1} and ± 3 degrees. The Vaisala HMP-45 (Vaisala, Helsinki, Finland) temperature/humidity probes are accurate to ± 0.4°C for temperatures ranging from -20 to 55°C and to ±2 percent for relative humidity (RH) ranging from 0 to 90 percent. Pressure is measured with the Vaisala PTB-101B, which has an accuracy rating of ± 2 hectopascal (hPa) over the temperature range of -20 to 45°C.

PWIDS data are processed by the Campbell Scientific (Logan, Utah) CR1000 data logger and forwarded via a FreeWave 1370-1390 megahertz (MHz) spread spectrum transceiver to the WDTC Weather Station via a radio link and then routed to the test site through the WDTC computer intranet or through a second radio network. PWIDS software displays aerial photographs or a computer-aided design (CAD) map of an area designated for data collection with meteorological parameters superimposed on the display. It also provides the user with a table of numeric data for collected parameters. Another feature of the software is the ability to display trend patterns for any given station. Automatic data archival is accomplished during data collection by directly porting information into a relational database.

WDTC deployed 31 PWIDS on the Jack Rabbit test. Three 32 m towers were deployed with PWIDS at the 2 m, 4 m, 8 m, 16 m, and 32 m levels for a total of 15 tower-mounted PWIDS. An additional 16 tripod-mounted PWIDS were deployed with four systems in each of the four cardinal directions. All data from the 31 PWIDS were viewable in real-time at the CP site. A photograph of the PWIDS is provided in Figure B.11, the PWIDS positions are illustrated in Figure B.12, and the geodetic coordinates for the stations are listed in Table B.8.

Figure B.11. Typical Portable Weather Information and Display System on a 2 m Tripod – Jack Rabbit Project

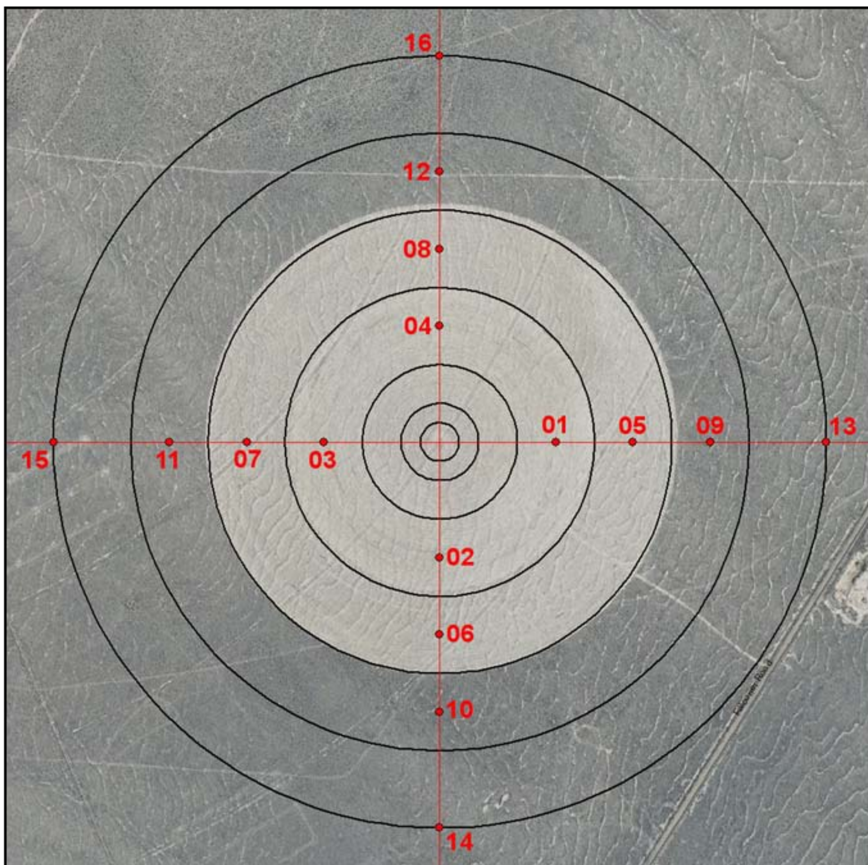

Figure B.12. Portable Weather Information and Display System Located at 150 m, 250 m, 350 m, and 500 m From Grid Center – Jack Rabbit Project

Table B.5. Portable Weather Information and Display System Geodetic Locations at 150 m, 250 m, 350 m, and 500 m From Grid Center – Jack Rabbit Project

2 M PWIDS POSITIONS	LATITUDE	LONGITUDE
01 (East 150 m)	40.2066502500	-113.263960293
02 (South 150 m)	40.2052663115	-113.265676541
03 (West 150 m)	40.2065812705	-113.267482718
04 (North 150 m)	40.2079661366	-113.265766492
05 (East 250 m)	40.2066732193	-113.262786149
06 (South 250 m)	40.2043658435	-113.265646576
07 (West 250 m)	40.2065582766	-113.268655681
08 (North 250 m)	40.2088663784	-113.265796483
09 (East 350 m)	40.2066961767	-113.261612003
10 (South 350 m)	40.2034656054	-113.265616557
11 (West 350 m)	40.2065352171	-113.269829812
12 (North 350 m)	40.2097666200	-113.265826476
13 (East 500 m)	40.2067305906	-113.259850782
14 (South 500 m)	40.2021152368	-113.265571622
15 (West 500 m)	40.2065006822	-113.271591023
16 (North 500 m)	40.2111169822	-113.265871468

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B.11 Thirty-two Meter METEOROLOGICAL TOWER

Three 32 m towers were used for the Jack Rabbit test. PWIDS and ultrasonic anemometers (sonics) were collocated on these towers at 2 m, 4 m, 8 m, 16 m, and 32 m heights. The PWIDS transmitted real-time data to the CP, but the sonic datasets were collected after each daily test event. The center 32 m tower was also used for photonic support, with a standard video camera mounted at the 10 m height of the tower.

A sonic anemometer consists of a transducer array containing paired sets of ultrasonic transducers designed to alternately transmit and receive pulses of acoustic energy, a system clock, and circuitry designed to measure transit time between the transmission and reception of acoustic signals between transducer pairs. Sonics typically have 2- or 3-dimensonal arrays for measuring two wind components or the full vector wind. The sonics used for Jack Rabbit are 3D R.M. Young model 81000 sensors. Sonic output includes wind components and speed of sound at a rate of 10 Hz. Sonic data were processed to produce wind and turbulence statistics and fluxes of heat and momentum.

The numbering convention for the 32 m towers differs slightly from other Jack Rabbit instrumentation. Because the towers run in a straight line, rather than a circular pattern, the numbering starts in the North and progresses to the South in ascending order. A photograph of the 32 m tower is provided in Figure B.13, tower positions are illustrated in Figure B.14, and the geodetic coordinates for the three 32 m towers are listed in Table B.9.

Figure B.13. Thirty-two Meter Meteorological Tower (Center Tower - 50 m from Grid Center) – Jack Rabbit Project

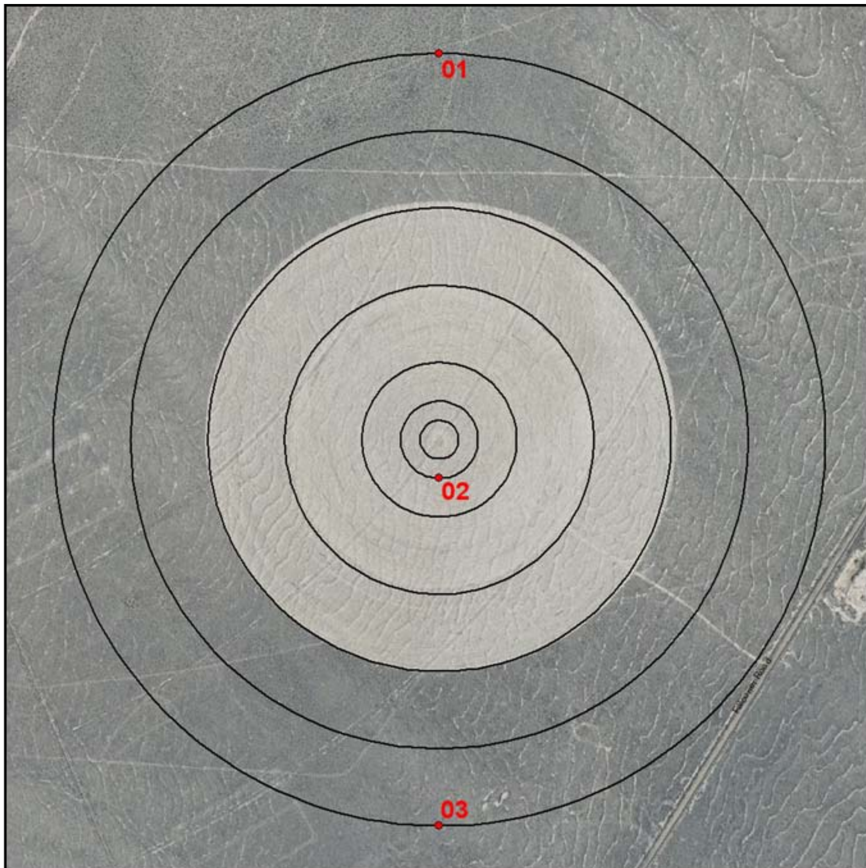

Figure B.14. Thirty-two Meter Towers Located at 50 m and 500 m From Grid Center – Jack Rabbit Project

Table B.6. Thirty-two Meter Tower Geodetic Locations at 50 m and 500 m From Grid Center – Jack Rabbit Project

THIRTY-TWO METER TOWER POSITIONS	LATITUDE	LONGITUDE
01 (North 500 m)	40.2111169791	-113.265871567
02 (Center 50 m)	40.2061663465	-113.265706536
03 (South 500 m)	40.2021152461	-113.265570839

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B.12 THERMOCOUPLES

WDTC deployed 24 thermocouple arrays on the Jack Rabbit test. Each array consisted of five thermocouple profiles with heights at ground level, 0.5 m, 1.0 m, 1.5 m, and 2.0 m AGL. Also on each array were two soil temperature thermocouples, which were buried at depths of 0.05 m and 0.1 m below ground level. Of the 24 arrays, four were deployed inside the depression. All of the arrays collected data at a 1-Hz rate and transmitted the data to the CP via a FreeWave 1370-1390 MHz radio network. The CP had a display for real-time monitoring of the thermocouple network.

During the Jack Rabbit test, thermocouple arrays were deployed at 25 m and 50 m from the grid center at 36-degree increments and within the depression at 90-degree increments. A photograph of the thermocouple array is in Figure B.15, thermocouple array positions are illustrated in Figure B.16, and the geodetic locations are provided in Table B.10.

Figure B.15. Thermocouple Array Located 25 m From Grid Center With Ammonia Disseminator in Background – Jack Rabbit Project

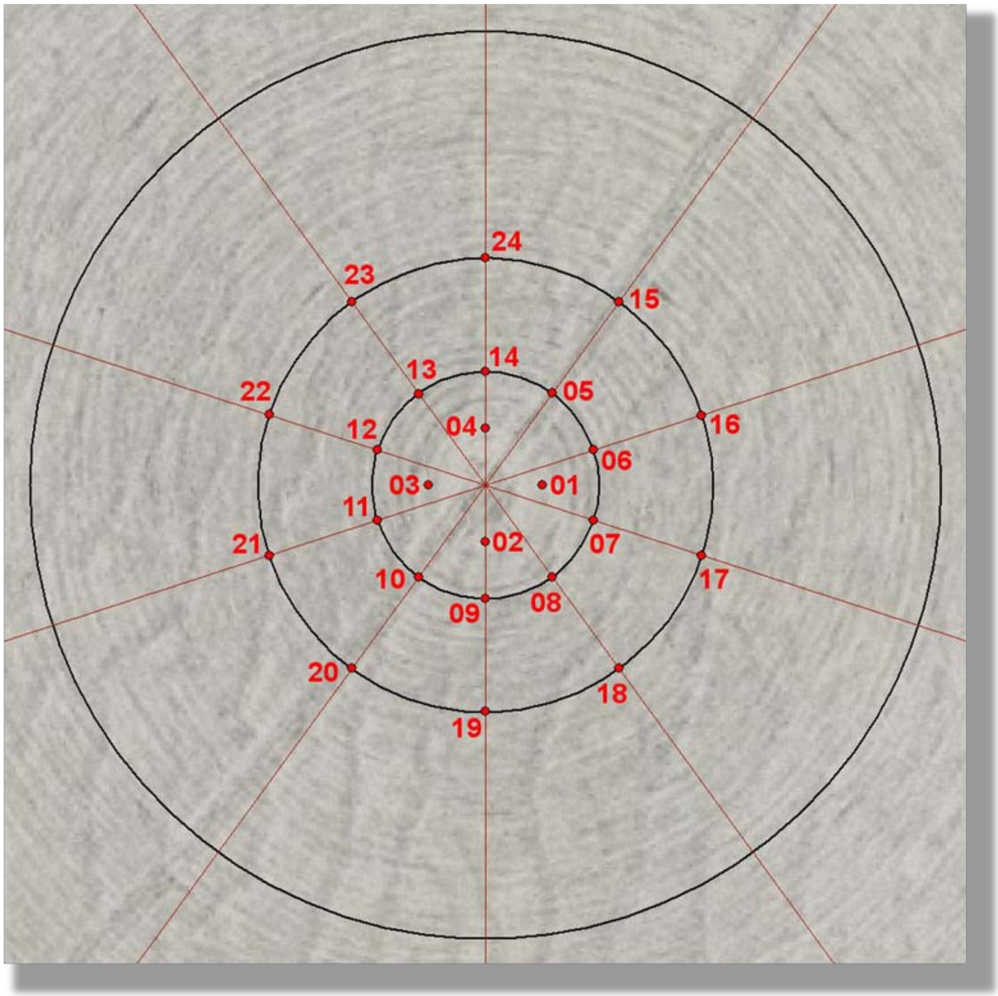

Figure B.16. Thermocouple Array Located at 25 m and 50 m From and Within Grid Center – Jack Rabbit Project

Table B.7. Thermocouple Array Geodetic Locations at 25 m and 50 m From and Within Grid Center – Jack Rabbit Project

THIRTY-TWO METER TOWER POSITIONS	LATITUDE	LONGITUDE
01 (East Depression)	40.2066186477	-113.265574739
02 (South Depression)	40.2065032434	-113.265717759
03 (West Depression)	40.2066128994	-113.265868275
04 (North Depression)	40.2067283039	-113.265725256
05 (Upper Northeast, 25 m)	40.2068010300	-113.265556293
06 (Lower Northeast, 25 m)	40.2066905754	-113.265445497
07 (Upper Southeast, 25 m)	40.2065518715	-113.265440877
08 (Lower Southeast, 25 m)	40.2064376115	-113.265543452
09 (South 25 m)	40.2063913930	-113.265714036
10 (Lower Southwest, 25 m)	40.2064308830	-113.265887484
11 (Upper Southwest, 25 m)	40.2065409853	-113.265997522
12 (Lower Northwest, 25 m)	40.2066796586	-113.266002143
13 (Upper Northwest, 25 m)	40.2067939333	-113.265899568
14 (North 25 m)	40.2068408341	-113.265729004
15 (Upper Northeast, 50 m)	40.2069860010	-113.265389204
16 (Lower Northeast, 50 m)	40.2067654885	-113.265168925
17 (Upper Southeast, 50 m)	40.2064878693	-113.265159683
18 (Lower Southeast, 50 m)	40.2062590464	-113.265364969
19 (South 50 m)	40.2061663465	-113.265706540
20 (Lower Southwest, 50 m)	40.2062452472	-113.266054094
21 (Upper Southwest, 50 m)	40.2064658110	-113.266274997
22 (Lower Northwest, 50 m)	40.2067438816	-113.266284260
23 (Upper Northwest, 50 m)	40.2069727986	-113.266078333
24 (North 50 m)	40.2070658947	-113.265736502

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B.13 ULTRASONIC (SONIC) ANEMOMETER

WDTC provided two sonic anemometers mounted on a 2 m tripod within the depression for turbulence characterization. The sonics used for Jack Rabbit were 3D R.M. Young model 81000 sensors. Sonic output includes wind components and speed of sound at a rate of 10 Hz. Sonic data were processed to produce wind and turbulence statistics and fluxes of heat and momentum. The survivability of this instrumentation was questionable in the harsh chemical environment to which it was exposed; however, the sensor and resulting dataset looked very good at the completion of the Jack Rabbit program.

A photograph of the anemometer is provided in Figure B.17, the anemometer positions are illustrated in Figure B.18, and the geodetic coordinates for the anemometers are listed in Table B.11.

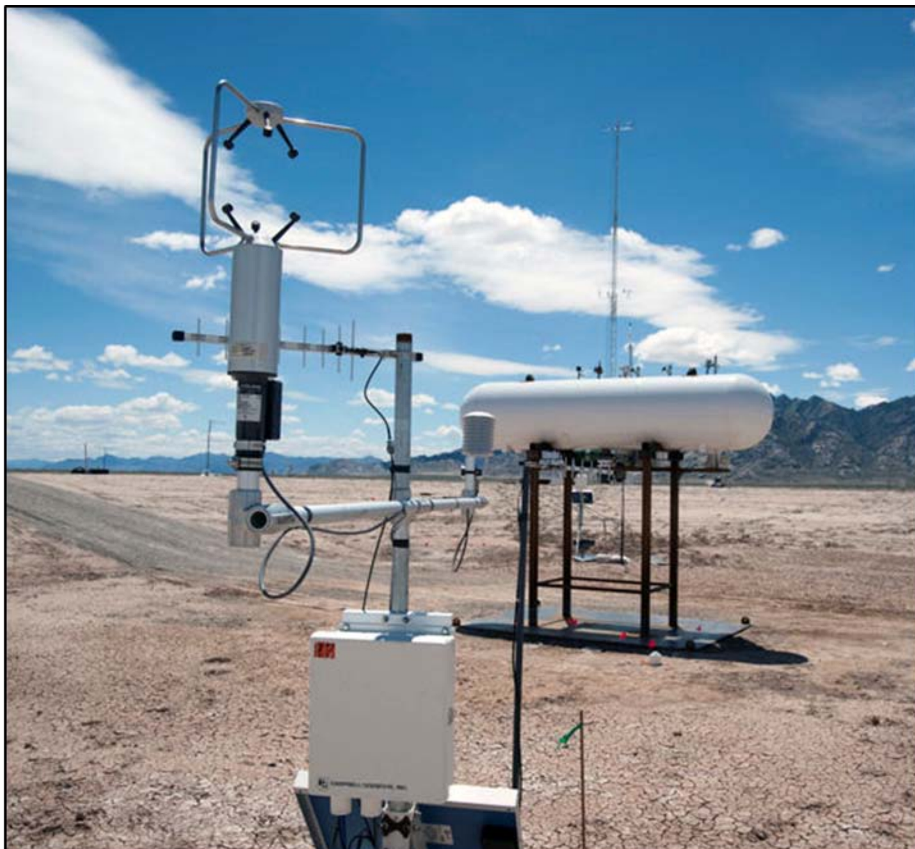


Figure B.17. Ultrasonic Anemometer Mounted on a Three Meter Tripod with Ammonia Disseminator in Background – Jack Rabbit Project

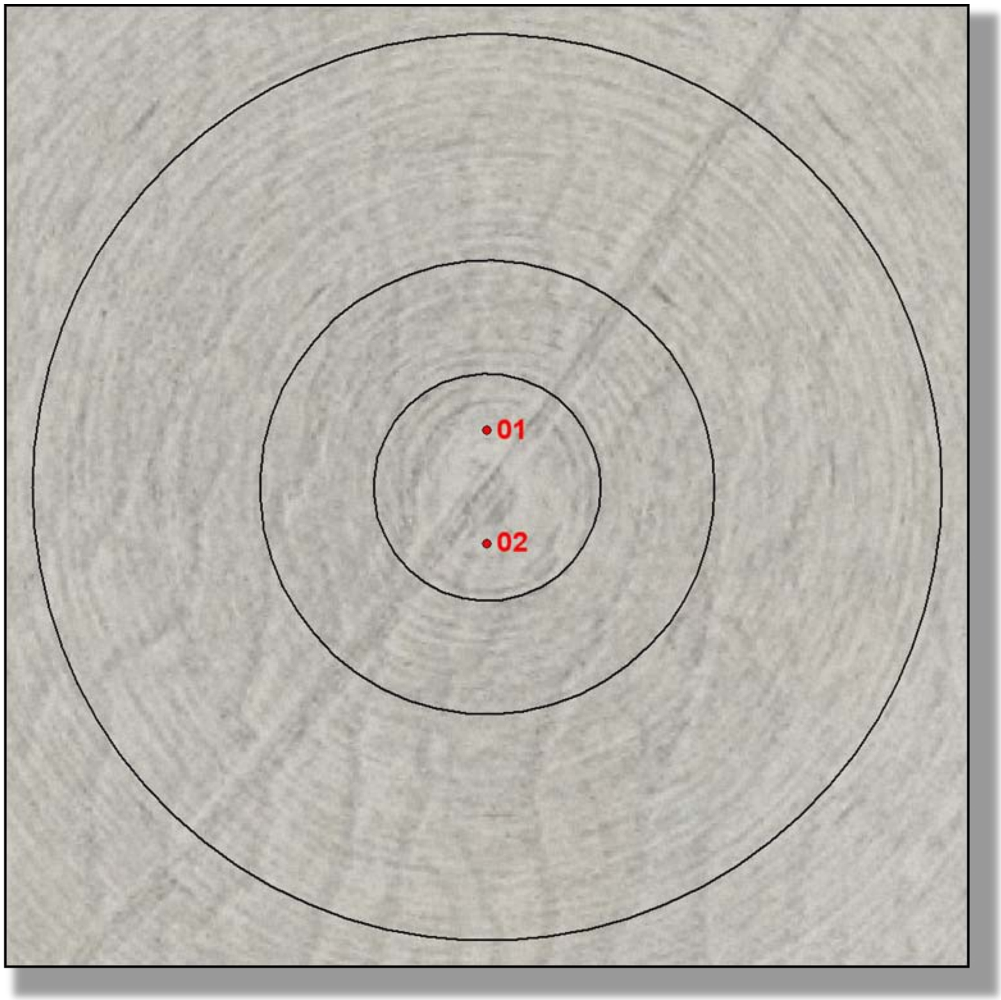


Figure B.18. Ultrasonic Anemometer Located Inside the Two Meter Deep Depression – Jack Rabbit Project

Table B.8. Ultrasonic Anemometer Geodetic Locations Inside the Two Meter Deep Depression – Jack Rabbit Project

ULTRASONIC POSITIONS	LATITUDE	LONGITUDE
01 (North Depression)	40.2067283039	-113.265725256
02 (South Depression)	40.2065032434	-113.265717759

B.14 DISSEMINATION SYSTEM

Two types of disseminators were designed and constructed by WDTC. One type of disseminator was built for anhydrous ammonia and another type was built for chlorine releases. Two identical disseminators of each type were built for a total of four disseminators. The anhydrous ammonia disseminator used a modified 1,000-gal propane tank, and the chlorine disseminators consisted of a modified 500-gal propane tank.

The dissemination valve assembly consisted of two valves: a manual knife gate valve and a remotely controlled ball valve. The knife gate valve provided increased safety for the WDTC dissemination crew because it separated the tank from the remotely controlled valve, and it remained closed until the disseminator was staged and ready to trigger.

A 4-in diameter valve assembly was used on the anhydrous ammonia disseminator, while a 3-in diameter valve assembly was used on the chlorine disseminator. A restricting orifice was attached to the outlet of each valve assembly to lessen the likelihood that flashing would occur during the rapid release of chemicals. The restricting orifice was used on the first four trials, but it was removed for the last six trials. The differences in tank sizes and valve assemblies allowed for approximately the same mass flow, whether the release was anhydrous ammonia or chlorine.

Tank pressure was monitored in the chemical liquid at the bottom of the dissemination tank and in the vapor head space at the top of the tank. Temperature within the tank was also monitored. Software was written to control the dissemination and valve operation from the CP site and record the pressure and temperature data.

The dissemination height was 2 m AGL. A stand was constructed to mount the disseminator at the desired height at the center of the depression. A second, shorter stand was built and mounted on the back of a crane to transport the dissemination systems before each trial. Photographs of the chlorine disseminator during construction are provided in Figure B.19.

Figure B.19. Ammonia Disseminator and Underneath of Disseminator Showing Remotely Controlled Valve Assembly – Jack Rabbit Project

B.15 OTHER INSTRUMENTATION/SERVICES

Paper Detection

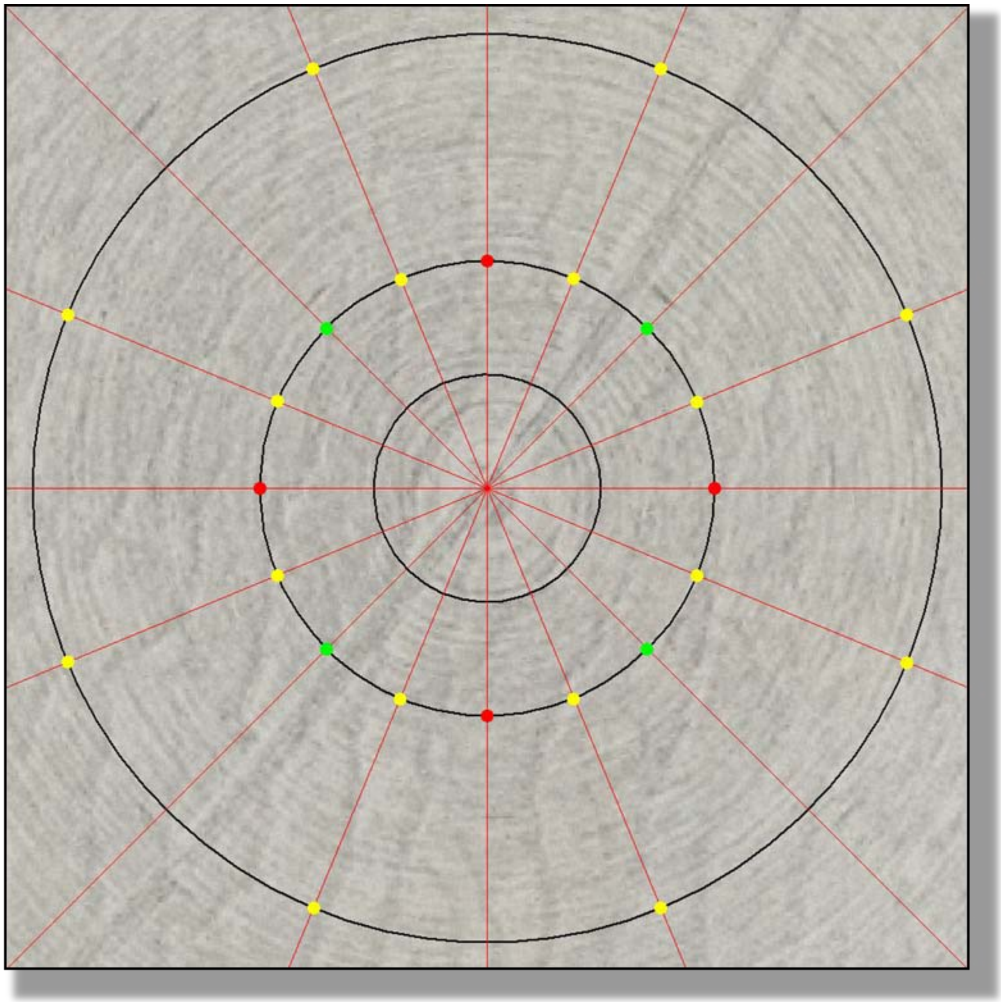
Within the 2 m deep by 50 m diameter depression, WDTC placed M8/M9 and common black construction paper at multiple locations. The intent for using the paper placement was to take a simple approach to the determination of vapor/aerosol and possible rainout within the chemical cloud. Although M8/M9 paper is primarily used for detection of nerve or blister agents, it also reacts with many other chemicals. The black construction paper would indicate droplets or rainout of the cloud. Currently, no commercially available chemical detection instrumentation exists for the high concentrations expected within the depression. Because of this, and with the approval of CSAC, WDTC opted for this simple method for cloud characterization. At the conclusion of the pilot test, this method was re-evaluated and it was decided not to use M8/M9 paper, but rather to use construction paper exclusively.

Modeling

WDTC provided real-time modeling of the downwind hazard using the Hazard Prediction and Assessment Capability (HPAC) software developed under the Defense Threat Reduction Agency (DTRA, Fort Belvoir, Virginia) sponsorship. Although HPAC is not actually a type of instrumentation, it is a valuable tool for use at the CP and has a verified and validated dense gas capability. In 2003, the U.S. Army Test and Evaluation Command (ATEC) mandated[6] that all test programs releasing any chemical or biological simulant will have near real-time modeling support during the conduct of the test in order to assess potential exposures to populated work areas downwind of the release location. During Jack Rabbit, an on-site meteorologist ran the HPAC model and provided the TO time series of model plots before, during, and after each of the releases. Templates for the HPAC model were constructed before the test conduct that simulated the type, duration, and amount of release. Meteorological data from the test grid were used as input into the HPAC model. These model results were provided in a matter of a few minutes upon request from the TO and in several cases were used to evacuate the camera positions and/or the CP before the threat of chemical exposure became relevant.

Collocations

Many chemical detection sensors were collocated to provide for instrument inter-comparison. Figure B.20 illustrates the chemical point detectors that were collocated.



NOTE: Yellow = bubbler/ultraviolet (UV) Canary collocation; Green = bubbler/Jaz UV-VIS collocation; Red = bubbler/UV Canary/Jaz UV-VIS collocation.

Figure B.20. Chemical Detector Collocation Sites – Jack Rabbit Project

APPENDIX C: Glossary of Abbreviations and Acronyms

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Glossary of Abbreviations and Acronyms

Table C.1. Abbreviations and Acronyms

ABBREAVIATION / ACRONYM	DEFINITION
2D	two dimensional
3D	three dimensional
3DCAV	three dimensional cloud analysis and visualization
A	ammonia
ADSS	ATEC Decision Support System
AFB	U.S. Air Force Base
AFRL	U.S. Air Force Research Laboratory
AGL	above ground level
APG	Aberdeen Proving Ground
APGEA	Aberdeen Proving Ground Edgewood Area
AreaRae	Wireless, multiple channel, multi-gas detector
ATEC	U.S. Army Test and Evaluation Command
ATTN	attention
C	chlorine
CAD	computer-aided design
CCD	charge-coupled device
CDR	critical design review
CFD	computational fluid dynamics
CL	concentration pathlength
COR	contracting officer’s representative
CP	control point
CSAC	Chemical Security Analysis Center
CTEH	Center for Toxicology and Environmental Health
DHS	U.S. Department of Homeland Security
DoD	Department of Defense
DPG	U.S. Army Dugway Proving Ground
DSN	defense switched network
DT	developmental test
DTC	U.S. Army Developmental Test Command
DTP	detailed test plan
DTRA	Defense Threat Reduction Agency
FCR	final command review
FTIR	Fourier-transform infrared (spectrometer)
gal	gallon
GB	gigabyte
GPS	global positioning system
HD	high definition
hPa	hectopascal

Table C.1. Abbreviations and Acronyms (cont)

ABBREAVIATION / ACRONYM	DEFINITION
HPAC	Hazard Prediction and Assessment Capability (software)
HQ	headquarters
Hz	Hertz
IAW	in accordance with
ICR	initial command review
IM – insensitive munitions	insensitive munitions
-in	inch
IR	infrared
IRIG-B	Inter-Range Instrumentation Group, Code B
ITOPS	international test operations procedure
LED	light-emitting diode
LLC	Limited Liability Corporation
LOI	letter of instruction
LW	longwave
m	meter
MB	megabyte
MDT	mountain daylight time
MHz	megahertz
MiniRAE	gas detector
NA	not applicable
ND	no data
NEPA	National Environmental Policy Act
NSWC	National Environmental Policy Act
OPSEC	Operations Security
ORI	operational readiness inspection
OSHA	Occupational Safety and Health Administration
P	Pilot test
PA	Pilot test using ammonia
PC	Pilot test using chlorine
PAM	pamphlet
PDR	preliminary design review
PID	photoionization detector
POC	point of contact
POSS	preoperational safety survey
ppm	parts per million
psi	pounds per square inch
PWIDS	Portable Weather Information and Display System
QC	quality control
R	record test

Table C.1. Abbreviations and Acronyms (cont)

ABBREAVIATION / ACRONYM	DEFINITION
RA	record test using ammonia
RC	record test using chloine
R-134a	tetra fluoroethane
RH	relative humidity
RS-232	Recommended Standard-232
S&T	Science and Technology
Sec	second/s
SME	subject matter expert
SSLLC	Signature Science, LLC
TC	test center
TCO	test control officer
TIC	toxic industrial chemical
TIH	toxic inhalation hazard
TO	test officer
TOPS	test operations procedure
TP	test plan
TRACE	Temporally Rendered Automatic Cloud Extraction
TRR	test readiness review
TSA	Transportation Security Administration
UTC	Coordinated Universal Time
UV	ultraviolet
UV-VIS	ultraviolet visible
VIS	visible
VISION	Versatile Information System Integrated Online Nationwide
VLW	very longwave
WDTC	West Desert Test Center

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APPENDIX D: References

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